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YOUTH'S COMPANION SERIES

TRIUMPHS OF SCIENCE

EDITED BY

M. A. L. LANE

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TRIUMPHS OF SCIENCE

THE STORY OF THE ATLANTIC CABLE

In 1853 an interesting scheme was brought to my attention. It was an attempt to resuscitate an enterprise that had been begun and had broken down, to carry a line of telegraph to Newfoundland, — including a cable across the Gulf of St. Lawrence, — and at St. John's to connect with a line of steamers to Ireland, by which the time of communication might be reduced to five days.

The project did not seem to me very formidable. It was no more difficult to carry a line to St. John's on this side than to some point on the Irish coast. But was this all that could be done?

Beside me in the library was a globe which I began to turn over to study the relative positions of Newfoundland and Ireland. Suddenly the thought flashed upon me, "Why not carry the line across the Atlantic?"

That was the first moment that the idea ever entered my mind. It came as a vision of the night, and never left me until, thirteen years after, the dream was fulfilled.

It is very easy to draw a line on a map or a globe, but quite another to measure out all the distances by land and sea. As I could not undertake it alone, I looked about for a few strong men to give it support.

My next-door neighbor was Peter Cooper, whose name is justly held in honor for his simple, noble life, and his great generosity to his native city. He had a genius for mechanics, as he showed by constructing one of the first locomotives in this country. Though an old man, he had not grown so conservative as to think that there was nothing new to be done in the world.

He was the first to join the enterprise, and stood by it through all its fortunes to the end. That helped me to enlist Moses Taylor, Marshall O. Roberts, and Chandler White, together with my brother, Mr. David Dudley Field,—six of us in all,—who made up the little company that undertook the telegraph to Newfoundland, as preliminary to the larger undertaking of crossing

the ocean itself. Mr. White died a few months later, and his place was taken by Mr. Wilson G. Hunt.

The title of "The New York, Newfoundland and London Telegraph Company" indicated the full scope of the design.

As soon as we had organized, three of us, Mr. White, my brother, and myself, started for Newfoundland to get a charter, which we obtained after some weeks' negotiation, giving us for fifty years the exclusive right to land a submarine cable upon those shores.

Now the work began in earnest. The first thing we had to do was to build a line of telegraph four hundred miles through an uninhabited country, cutting our way through the forests, climbing hills, plunging into swamps, and crossing rivers.

When we came to the Gulf of St. Lawrence we had our first experience in laying a submarine cable. It was but a short line, less than a hundred miles long, and yet we failed even in that; and the attempt had to be renewed the following year, when it was successful.

Of course we felt a great satisfaction that we had got so far. We had crossed the land, but

could we cross the sea? As we stood upon the cliffs of Newfoundland and looked off upon the great deep, we saw that our greatest task was still before us.

For this we had been preparing by preliminary investigations. Before we could embark in an enterprise of which there had been no example, we must know about the ocean itself, into which we were to venture. We had sailed over it, but who knew what was under it? The cable must be on the bottom; and what sort of bottom was it? Smooth and even, or rugged as Switzerland, now sinking into deep abysses, and then rising in mountain chains over which the cable must hang suspended, to be swept to and fro by the deep undercurrents of the ocean?

Fortunately just then careful soundings by English and American navigators showed that the ocean bed was one vast plain, broader than the steppes of Siberia or the prairies of America, reaching nearly from shore to shore; and in their surprise and joy the discoverers christened it the "telegraphic plateau," so much did it seem like a special conformation of the globe for the service of man.

Giving it that name, however, did not prove that a cable could be laid across it. The mechanical difficulty alone was enormous. Men had stretched heavy chains across rivers as booms to bar the passage of ships, but who ever dreamed of a chain over two thousand miles long?

If it could be drawn out to such a length, would it not fall in pieces by its own weight? Suppose all went well, and it should hold together long enough to be got safely overboard, and to be dropped in the ooze of the ocean bed, what would it be good for?

There rose the scientific difficulty: Could an electric current be sent through it? The fact that a cable had been laid across the British Channel, so that it was possible to telegraph from Dover to Calais, was no proof that a current could be sent across the whole breadth of the Atlantic.

To get an answer to this question, we appealed to the greatest authorities in both countries. Morse said, "Yes, it can be done." So said Faraday; and when I asked the old man, "How long will it take for the current to pass from shore to shore?" he answered, "Possibly one second!"

Such words of cheer put us in good heart and hope, and yet the only final and absolute test was that of experiment. And a very costly experiment it must be.

To make such a cable as we required, and to lay it at the bottom of the sea, would cost six hundred thousand pounds sterling, — three millions of dollars! Where was all that money to come from? Who would invest in such an enterprise?

I went from city to city, addressing chambers of commerce and other financial bodies in England and the United States. All listened with respect, but such was the general incredulity that men were slow to subscribe. To show my faith by my works, I took one fourth of the whole capital myself. And so at last, with the help of a few, the necessary sum was secured and the work began.

The year 1857 saw the cable on board of two ships furnished by the governments of England and the United States; but these ships were hardly more than three hundred miles from the coast of Ireland when the cable broke, and they had to return. So ended the first expedition.

The next year we tried again and thought we could diminish the difficulty and the danger by beginning in the middle of the Atlantic, and there splicing the cable, when the two ships should sail eastward and westward till they should land the two ends on the opposite shores. This plan was carried out. They reached mid ocean, and, splicing the cables together, the ships bore away for Ireland and Newfoundland, but had not gone a hundred miles before the cable broke. Several times we tried it with the same result. Then a storm arose, in which one of the ships, the "Agamemnon," came near foundering; and at last all were glad to get safely back again into the shelter of an English port.

I went to London to attend a meeting of the board of directors. It was not a very cheerful meeting. On every face was a look of disappointment. Some thought that we had done everything that brave men could do, and that now it was time to stop. To make another attempt was folly and madness. So strong was this feeling that when the more resolute of us talked of renewing the attempt, the vice president rose and left the room.

It was then that we took courage from despair. We had failed already; we could not do worse than fail again! There was a possibility of success; it was indeed a forlorn hope, but we would try it.

Again the ships put to sea, but there was little enthusiasm, for there were few in either hemisphere who expected anything but a repetition of our former experience. Such was the state of the public mind when, on the 5th of August, 1858, it was suddenly flashed over the country that the "Niagara" had reached Newfoundland, while the "Agamemnon" had reached Ireland, so that the expedition was a complete success.

The revulsion of feeling was all the greater from the previous despondency, and for a few weeks everybody was wild with excitement. Then the messages grew fewer and fainter, till at last they ceased altogether. The voices of the sea were dumb.

Then came a reaction. Many felt that they had been deceived, and that no messages had ever crossed the Atlantic. Others, while admitting that there had been a few broken messages, yet concluded from the sudden failure that a deep-sea

cable must be subject to such interruptions that it could never be relied upon as a means of communication between the continents.

A year or two later a company was formed to construct a land line along the western coast of America, with the design that from the far northwestern coast it should be strung along from one stepping-stone to another, by the Aleutian Islands, till it should come within easy distance of Siberia, the whole breadth of which must be crossed. In this way Europe might at last be reached by way of Asia!

This vast undertaking was actually begun and carried forward with great energy till it was stopped in mid career by the success of the Atlantic cable; but for this we had to wait seven long years. Our country was plunged in a tremendous civil war and had no time to think of the enterprises of peace.

In these years ocean telegraphy had made great progress. Other facilities we found that we had not before. The "Great Eastern," which from its enormous bulk had proved too unwieldy for ordinary commerce, was the only ship afloat that could carry the heavy cable; the whole was coiled

within her sides, and with the mighty burden of twenty thousand tons she put to sea.

Never had there been such a prospect of success. For twelve hundred miles she rode the sea in triumph, till in a sudden lurch of the ship the cable snapped, and once more all our hopes were

In the deep bosom of the ocean buried.

For one whole month we hung over the spot trying to raise the cable, but in vain; and again we took our "melancholy way" back across the waters which had been the scene of so many failures.

This last disaster upset all our calculations. Our cable was broken and our money was gone, and we must begin all over again.

Fresh capital had to be raised to the amount of six hundred thousand pounds. That single lurch of the ship cost us millions of dollars and the delay of another year.

But time brings round all things, and the next year, 1866, the "Great Eastern," laden with a new burden, once more swung her mighty hulk out on the bosom of the Atlantic. For fourteen days she bore steadily to the west, while we kept up our communication with the old world that we had left behind.

Toward the end of the voyage we watched for the land as Columbus watched for the first sign of a new world. At length, on the twenty-seventh day of July, we cast anchor in Trinity Bay in the little harbor of Heart's Content, that seemed to have been christened in anticipation of the joy of that hour.

All the ship's crew joined to lift the heavy shore end out of the "Great Eastern" into the boats, and then to drag it up the beach to the telegraph house, where every signal was answered from Ireland, not in broken utterances, as with the old cable, but clearly and distinctly, as a man talks with his friend; and we knew that the problem was solved, and that telegraphic communication was firmly established between the old world and the new. But our work was not quite ended. There was the last year's cable with its broken end lying in the depths of the sea. As soon as the work of unloading the "Great Eastern" was done, she bore away to grapple for the lost cable. It was not difficult to find it, and again and again we grappled it; but it was not an easy matter to bring up such a weight from a depth of more than two miles.

Sometimes we caught sight of it as it was held by our grappling irons; but the strain was tremendous, and the nearer we drew it to us the more it writhed like a sea serpent, till it broke away and plunged into the sea. This happened many times; but at last, after repeated trials, it was caught and held so firmly that it could not escape, and, being spliced with the cable on board, it was paid out safely to the shore of Newfoundland.

Thus not one but two cables were laid across the Atlantic.

Since that time, now more than a quarter of a century ago, telegraphic communication has not been interrupted for a single day.

In looking back over these eventful years, I wonder how we had courage to carry it through in the face of so many defeats and of almost universal unbelief. A hundred times I reproached myself for persisting in what seemed beyond the power of man. And again there came a feeling that, having begun, I could not turn back; at any cost I must see it through.

At last God gave us the victory. And now, as we see its results, all who had a part in it must feel rewarded for their labors and their sacrifices.

That iron chain at the bottom of the sea is a link to bind nations together. The magnetic currents that pass and repass are but the symbols and the instruments of the invisible yet mighty currents of human affection that, as they pass to and fro, touch a thousand chords of love and sympathy, and thus bring into nearer, closer, and sweeter relations the separated members of the one great family of mankind.

CYRUS W. FIELD.

A MODERN OBSERVATORY

I HAVE lived in an observatory for about twenty years now, and I have seen all sorts of visitors and have heard all sorts of questions asked — intelligent ones and otherwise. But there are two classes of people who are always interested and who always go away satisfied. It is a pleasure to see them. These classes are bright, clever schoolboys, and good artisans and mechanics.

The mechanics invariably find pieces of machinery which are built according to principles which they understand; hence they are interested and instructed. The boys, if they are intelligent and willing to ask questions, always see much that is suggestive and that helps to explain *how* the things are done which they know *are* done; how it is, for example, that astronomers can determine the position of a star — its celestial latitude and longitude.

Some of the older visitors do not seem to get on so well. They often have a confused notion

that they are expected to comprehend everything that they see, and a queer little vanity in not being frankly ready to ask for information.

One such visitor was taken into the great dome of the Lick Observatory, which was tightly closed to keep out the rain. It is built of steel and is about as solid a construction as one can conceive. This visitor looked at the telescope, and then up at the dome, and evidently was puzzling over the question of how one could see through this dome, when finally he asked his guide, "Is the dome *transparent?*"

That was about the same as asking some one to tell you if you could see through a brick wall. If he had asked the natural question, "How do you see the sky through this telescope when it seems to be tightly shut up inside an iron house?" he would have been told that a part of the roof could be moved so as to leave a clear open window, nine feet wide, all the way from the horizon to the zenith; and furthermore that the whole dome could be turned round so as to point this window in any direction, — east, west, north, south, — which practically amounts to being able to take the roof off altogether. But "*transparent!*"

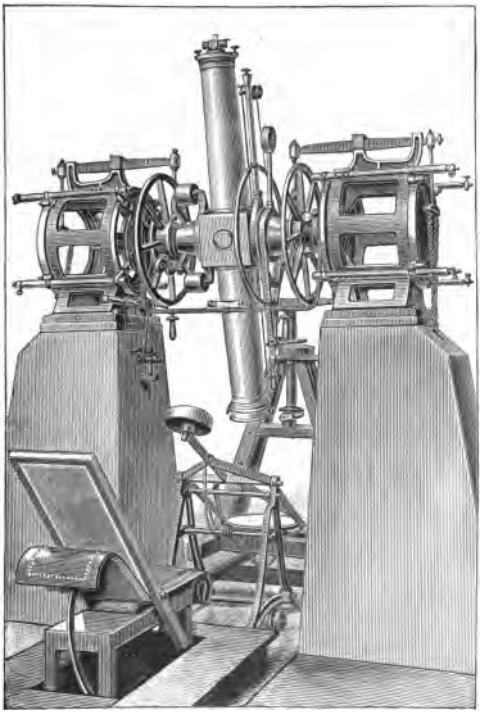
As there are not so very many astronomical observatories in the world, I have been asked to give some account of one, so that any one can read about what he may not be able to see for himself.

I shall, then, describe the most important parts of a modern observatory, and tell what the principal instruments are for. The picture opposite will help to explain one of them.

In this machine, which is called the "meridian circle," the axis is horizontal and points exactly east and west. The telescope must then revolve exactly in the meridian. In the picture it is pointing downward, so as to see a star reflected in the basin of quicksilver. Usually it is pointed directly at the star we wish to observe. There are two circles on the axis, divided into degrees, etc. Four long horizontal microscopes read each circle, and thus fix the latitude of the star. A level is hanging below the axis so as to test whether the axis is horizontal.

This looks like a very complicated machine, and it really is so; but the principles of it are quite simple. It is used to do two things: to determine the longitudes and the latitudes of stars.

As the axis is horizontal and points exactly east and west, the telescope must trace out the meridian on the sky when the axis is revolved.

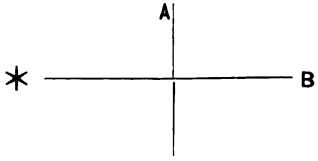


Suppose the left-hand side of the picture is *east*. All the stars on that side will be rising and moving toward the west, and every one of them will

cross the meridian halfway between its own rising and setting.

Suppose that we point the telescope to Sirius just before it reaches the meridian. It will appear in the field of view of the telescope and slowly move across it in the direction of the arrow, thus: → * * *

Now in the eyepiece there is a pair of crossed spider lines. The telescope is moved so that the star passes exactly along the spider line B.



The instant the star reaches the vertical spider line A the observer notes the exact hour, minute, second, and fraction of a second by a clock which is ticking near him, within hearing.

Suppose he noted this time for Sirius to be $6^h\ 40^m\ 0^s.0$. Now his observation at the telescope is done. He rises and goes to one of the long horizontal microscopes, — there are four of them on each side in the picture, — and looks through it at the circle. The circle is divided into degrees, etc., and the observer notes that the microscope reads, for Sirius, say $10°\ 0'\ 0''.0$.

Now let us suppose another star, x, to come up to the meridian from the east. The telescope is again moved so that x moves along the horizontal wire B, and the time is noted when x crosses the vertical wire A. Suppose this time is $7^h\ 0^m\ 20^s.5$. It is clear that this star is $20^m\ 20^s.5$ east of Sirius. ($7^h\ 0^m\ 20^s.5$ is $20^m\ 20^s.5$ later than $6^h\ 40^m\ 0^s.0$.) The observer rises and reads the circle for the star x just as he read it for Sirius. Suppose the circle reads for x $15°\ 10'\ 13''.5$; then x is $5°\ 10'\ 13''.5$ north of Sirius.

Now if we know the latitude and longitude of Sirius, we have only to add $20^m\ 20^s.5$ to its longitude and $5°\ 10'\ 13''.5$ to its latitude to get the longitude and latitude of the previously unknown star x.

The principle is quite simple and clear. The details of the process are extremely complicated, but we need not say anything about them here. In fact, they are nothing but details and of no special interest except to the professional astronomer. If you ever have occasion to learn them, they can be learned, like anything else, by paying attention.

Just now the main point is to see that in this particular instrument — the meridian circle — we have a means of determining the exact position, longitude and latitude, of any and every star.

One more thing is needed to describe completely a star as seen in a telescope. We must know not only its position, but also its brightness.

We call the brightest stars, like Sirius, of the first magnitude. The faintest stars that can be seen with the naked eye are of the sixth magnitude. The faintest stars visible in a two-inch spyglass are of the tenth magnitude, and the faintest stars we can see in our great telescope at Mount Hamilton, whose object glass is three feet across, are of the seventeenth magnitude.

The observer carries in his memory a scale of magnitudes, and when a new star, x, comes into the field of the telescope he notes that x is, for example, of the 7.5 magnitude.

A catalogue of stars is nothing but an orderly list of many stars, for each one of which is given three things, — brightness, longitude, latitude.

We can determine the time with a meridian circle. We know beforehand the exact time at which a star like Sirius ought to cross the meridian.

We observe it crossing and note the exact time by some clock when it really does cross. The difference of these two times is the correction of the clock.

The great Lick telescope was mounted in 1888, and was then the largest in the world. The object glass is three feet in diameter, and the tube is fifty-seven feet long. The telescope and mounting weigh thirty-seven tons, and the parts that move weigh nearly four tons. The highest magnifying power used on stars is about five thousand times. It is so arranged that photographs can be taken with it also.

The meridian circle can view a star only for the brief moments while the star is passing from east to west across the meridian. The instant it has left the field of view it is lost to sight until the next day, and then, again, it can be seen only for a moment. But some stars we wish to examine for a long time continuously; this is especially true of planets.

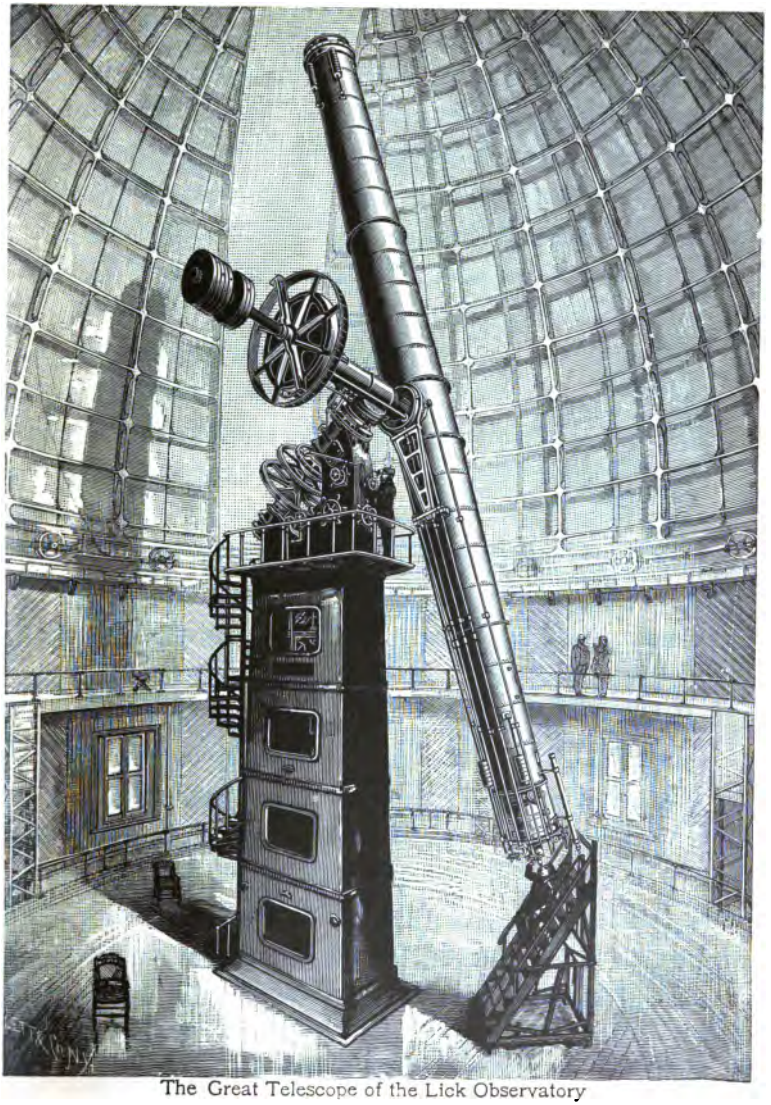
We wish to point a telescope at them shortly after they rise in the east and study their appearances during the whole of a long night, until they have sunk low in the west.

To do this we must contrive a suitable mounting for our telescope. The small telescope stands with three legs, such as every one has seen, will do for this purpose, but a much better form is the equatorial mounting, as it is shown in the pictures of the great telescope at Mount Hamilton.

Here the telescope is directly attached to the latitude axis. Near the end of this axis is a divided circle, and the latitude of the star you wish to find is set off on this circle by moving the telescope. You are now pointed to the right latitude. The inclined axis just above the heavy iron stand is the longitude axis, and it also is provided with a circle. By turning the whole telescope, latitude axis and all, around this, the right longitude can be reached, and the star is seen in the eyepiece.

But the star is constantly moving from east to west, from rising to setting, and the telescope must also be moved to follow it. There is a provision for this too.

There is a powerful clock in the uppermost section of the iron pier of the telescope mounting. If we start this clock and attach it, by merely turning a handle, to the telescope, we can make



The Great Telescope of the Lick Observatory

it drive the whole tube slowly from east to west, from rising to setting.

If, for instance, the telescope is pointed to the sun about sunrise, and if the clock is kept wound up, the telescope will, of itself, follow the sun all day and will point directly to it at sunset. And it will do this accurately for any star.

This is an enormous convenience in making visual observations, for it saves the observer the trouble of moving the whole telescope to follow the star, which is continually moving from rising to setting.

When we come to photographing the stars the clock is a still greater convenience. We want each star to make a neat round dot on the photographic plate, even if the exposure is quite long, several hours, for instance. Hence it is absolutely essential to have the telescope and the photographic plate follow the star precisely during the whole exposure.

The use of a telescope mounted equatorially is to examine stars or planets at leisure, and for as long as one wishes. The planet is brought to the middle of the field of view and kept there by the clock.

The object glass of the telescope is up at one end of the tube, and an eyepiece at the other. The chief use of the tube is to keep these two things at exactly the right distance apart. The object glass makes a picture of the planet close down by the eye end, and the eyepiece is a microscope with which we examine the picture.

Eye End of the Lick Telescope

We have a whole set of eyepieces, some magnifying as much as five thousand times, and some only two hundred times, and we choose that one which gives the best results.

If the stars are quiet and do not twinkle, we can use a high power. If they do twinkle, we magnify the twinkling just as we magnify the star, and it is easy to magnify too much.

It is the unsteadiness of the air that sets a limit to the amount of magnifying. The reason the Lick Observatory was placed where it is, on the very top of Mount Hamilton, was because the

stars were found to be unusually steady at this point, and also because an unusual number of days and nights were free from clouds.

We find that we can often use a magnifying power of one thousand on the moon, and this brings the moon to within two hundred and forty

Mount Hamilton and the Lick Observatory

miles of the earth, because its real distance is two hundred and forty thousand miles. On rare occasions we can bring the moon even closer.

The most important work which has been done with the great telescope at Mount Hamilton is

the photographing the spectra of the stars. In visual observations we let the object glass form a picture of the object, and we examine this picture with a microscope, an eyepiece. In spectrum observations we let the light from the object glass pass through one or more prisms, and change the image from a picture into a rainbow-tinted streak of light, red at one end and violet at the other, and crossed by a number of very fine, narrow, dark lines.

Every star, and the sun, has a set of such lines peculiar to itself. Every chemical substance — as hydrogen, sodium, quicksilver, etc. — also has a set of lines peculiar to itself.

We find out which lines belong to hydrogen, for example, by experiments in a laboratory. Observations on a star sometimes show us these same lines in the star spectrum. Hence it follows that the star is partly composed of hydrogen.

In the same way we can identify other substances in the star, and finally can give a fairly complete list of its elements.

We can do a far more wonderful thing. Sometimes the lines of hydrogen in the star are present indeed, but they are slightly, very slightly, shifted

away from their true positions. We are absolutely sure the lines correspond to hydrogen. But what causes the shift in their positions?

It is caused by the motion of the earth toward the star, or, if the shift is the opposite way, then by the earth's motion away from the star. This conclusion is a little too complex to be fully explained here, but an idea of it may be had through a familiar and analogous case.

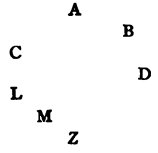
When you are in a railway train rapidly passing another one, you have noticed the peculiar shriek of the bell of the other engine. The sound of that bell is shifted to a higher note as you approach the train and to a lower one as you gradually pass away from it. Nothing is more certain than that the bell itself always gives out one and the same sound. The shift of the tone is caused by your motion, and the amount of the shift depends on the velocity of the motion.

The case is similar for light. If the lines are shifted one way, toward the blue end of the spectrum, we are approaching the star; if they are shifted the other way, toward the red, we are receding. The amount of the shift can be measured, and tells us how great our motion is.

Hence this device enables us to solve this amazing problem: Given a star bright enough to be seen, but so distant that it is hopeless even to guess how far off it is; required to find out how fast we are approaching this star in miles per second!

How should you like to meet this question in your next examination paper? But here is another one: Given that such determinations can be made; required to know how fast the whole solar system is moving in space, and in what direction!

You can solve this as follows: Suppose you measure how fast you are approaching or receding from a great number of stars scattered all round the sky. You are approaching star A at ten miles per second, B at nine, C at eight, etc.; and you are leaving star L at one mile per second, M at two, N at three, etc. Now if you had a map of all these stars as below,



you could see that it would be possible to draw a line among them which would show your *direction* of motion (toward A away from Z), and that

it might be possible to calculate the rate at which you were moving. In fact it is; and this problem —to find out how fast the earth (and the solar system) is moving in space—is the chief problem at Mount Hamilton to-day.

It is on our examination paper, and we expect to get an answer that will "prove."

It may not be very easy to follow this explanation of the process, but it is worth a little trouble to understand the astonishing questions which can be solved by modern scientific methods, using modern scientific instruments.

In what has gone before I have described some of the work and some of the instruments of a modern observatory. The buildings of such an establishment are designed to give the instruments and the observers every chance to do the best work.

All the foundations for the telescopes go down to the solid rock. All the observing rooms are ventilated so that the temperature inside the room is the same as that of the outside air. See if you can decide why it is that such an arrangement makes the stars twinkle less than they

would if the observing room were heated by a stove.

On the other hand, all the fine astronomical clocks are kept in a room which can be warmed to one temperature winter and summer, because such clocks run better at a constant temperature.

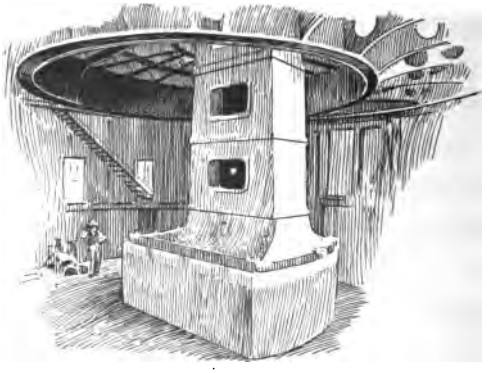
The domes and the machinery are arranged on the best mechanical principles, so as to move easily and spare the observer all useless trouble, — there is enough trouble that he must take anyway, — and, finally, every convenience is provided to save time and labor.

I think it is a fine thing that a private citizen like Mr. Lick has been able to use a part of his large fortune in building one of the greatest observatories in the world, in one of the best situations, and in providing it with the very finest instruments for work. This observatory is a department of the State University of California, and graduate students are received here to learn and practice their profession.

There is an astronomical society of amateurs which meets here regularly, and besides this there

are several thousands of visitors every year. The object of the whole institution is to be useful to mankind by advancing pure science and by diffusing the knowledge so gained.

EDWARD S. HOLDEN.



ASTRONOMICAL PHOTOGRAPHY

IT is safe to say that the application of photography to astronomy has, within the last twenty years, effected a change almost as great as that which followed the invention of the telescope by Galileo.

At present, indeed, the eye maintains its superiority in certain cases, as, for instance, in the study of planetary surfaces, in the measurement of close double stars, and in the so-called "observations of precision" for determining the absolute positions of the fundamental stars which are the points to which are referred the apparent motions of all the heavenly bodies.

But in the making of star charts, in the study of clusters and nebulæ and the physical characteristics of comets, in the discovery and observation

of variable stars, and especially in the study of stellar spectra, where the faintness of the light so narrowly limits the power of the eye, — in all these fields photography now reigns practically supreme. In fact, the only field which it seems unlikely soon to appropriate is the investigation of objects which are moving swiftly, or changing rapidly in form, and yet are so faint as to require a long exposure.

The chief advantages of photography are twofold: one is the fact that, with a telescope of given size, objects which cannot be seen at all through it can be photographed by simply prolonging the exposure. The eye gains nothing by protracted gazing. But with the sensitive plate it is different: if the object fails to impress itself in one minute, it may in ten; if not in ten minutes, an hour may answer. If necessary, the exposure may be lengthened to many hours.

Theoretically an object may be so faint that its light will never affect a plate of given sensitiveness, however long the exposure; but thus far in practice the limit has not yet been found. In connection with this it is also to be noted that the photographic plate is sensitive to ultraviolet rays not visible to the human eye. Now in certain

objects like the nebulæ and the tails of comets these rays are especially abundant, and in such cases the photograph brings out important and significant features which are otherwise beyond our power of observation.

The second most important advantage of photography is the permanence and completeness of its record — a record which can be referred to at any subsequent time with absolute confidence. The few minutes of fair weather and favorable conditions during which the exposure was made become virtually an eternity for all the purposes of observation. Nor is the study of the plate limited to any one person; it may pass under a dozen different inspectors, each of whom may detect some object or peculiarity which had escaped his predecessors.

A most remarkable exemplification of this advantage is the way in which the image of the newly discovered Eros was hunted down on plates made several years ago at Cambridge and in South America, although the presence of the planet had escaped notice until the mathematical astronomer, Dr. Chandler, had calculated the position near which it would be found.

There are of course certain disadvantages which, for the present at least, partly offset the great advantages we have pointed out. In the first place, since, as a rule, long exposures are generally needed, the perversity of our atmosphere is even more mischievous than in visual observations. The image of a star dances about so that the final result is usually a blotch, and not a point, and stars near together fuse into one. To this is added the effect of what is called "photographic irradiation,"—the spreading of the chemical action from each center of gravity.

For these reasons absolutely sharp definition is seldom, if ever, reached in astronomical photographs, and they are at present unavailable, as has already been implied, for the delineation of delicate details on the surface of a planet, or for measurements on close double stars. But it is quite possible that improvements in our plates may so shorten exposures and diminish irradiation as greatly to lessen this difficulty.

In another way visual observations have in certain cases a considerable advantage. The eye can utilize the occasional moments of good seeing, and build up a picture and description from what

is seen during those fleeting instants, disregarding the confused "mess" which alone is visible most of the time. The photograph, on the other hand, is only, as some one has said, "a brutal copy" and summation of all the confused appearances which presented themselves while the plate was under fire. It continually happens that, out of a dozen negatives, — of the moon, for instance, — taken in rapid succession on a fairly good night, not more than one will be worth preserving.

Another unfortunate circumstance is that our photographic plates are not equally sensitive throughout the range of differently colored rays, and are especially insensitive to the yellow and red portions of the spectrum. Even the best of the isochromatic and orthochromatic plates are far from satisfactory in this respect, and what sensitiveness they have for the red and yellow is gained at a great sacrifice in the blue and violet.

Then, too, the length of exposure required for most purposes demands a mechanical perfection of instrument and clockwork not easy to attain — far greater than is needed for visual work. The labor and skill required for the proper development of the negative also enter heavily into the

account; and after it is obtained it must, in most cases, be "measured up" under a microscope in order to extract the information it contains. The photographic observer is separated from his final result by several steps which do not intervene in the case of visual observations — just as the organist is farther from his music than the singer.

The first instruments used in astronomical photography were ordinary telescopes, and the then great fifteen-inch equatorial at Cambridge was the one with which the elder Bond, in 1850, obtained the first photographs of stars and of the moon; later also — in 1858 — of the great comet of that year. De la Rue in England, in the later fifties, followed up the work with a reflecting telescope, and succeeded in obtaining some excellent pictures of the sun and moon. In 1864 Rutherfurd, in New York, constructed the first "photographic refractor," with an object glass specially adapted to the purpose, and with it made photographs of the sun, moon, and many star groups. His negatives were admirable and have been but little surpassed by his most skillful successors.

Up to 1870, however, the possibilities of the art were greatly limited by the fact that the plates then used were sensitive only while moist, so that the length of exposure could not exceed four or five minutes. The introduction of dry-plate processes has removed that difficulty, and the constantly progressive increase in the sensitiveness of our plates has continually opened new and wider fields of operation.

The instruments at present in ordinary use in celestial photography are of three kinds. For certain purposes, as, for instance, for the photography of nebulæ, the reflector answers extremely well. Besides being much cheaper than any form of refracting telescope of equal power, the reflector possesses the capital advantage that it is absolutely impartial in its treatment of rays of every color — red, green, and violet rays all come harmoniously to the same focus and coöperate to form the image of the object.

On the other hand, its mirror is very likely to tarnish; its performance is more injured by slight inaccuracies of form and by distortions due to changes of temperature and position; and its field of view is very small, so that it can produce

satisfactory negatives covering at most an area only two or three times as great as the disk of the moon.

The second form of instrument is in appearance an ordinary refracting telescope, differing only in having an object glass so constructed as to bring to an accurate focus the violet rays which are specially efficient in photography. With the kinds of glass which alone were available until very recently, it is not possible to construct lenses which bring rays of all colors to a common focus; we are obliged to content ourselves with obtaining the best practicable result for the most effective rays. An object glass constructed primarily for purely visual purposes can, however, be made to perform very well for photography by the addition of an extra lens called a "photographic corrector." But it is generally better to construct the photographic telescope without reference to visual use.

Within a few years several new kinds of glass have been invented, and it is now theoretically possible to make object lenses that are nearly as impartial to color as are reflectors; but great practical difficulties still remain.

A very large proportion of all celestial photography thus far has been done with instruments of this general class — that is, with refracting telescopes having a "photographic object glass." The principal objection to this form of instrument is that its field of view, although much larger than that of a reflector of the same size, is still too small, seldom exceeding two degrees in diameter.

The third class of photographic telescopes differs from the second in substituting for the simple two-lens object glass a "doublet" consisting of two compound lenses at some distance apart, each made up of two or more component lenses — a regular camera lens, in fact, but generally much larger and of longer focus than is usual. Some of Professor Barnard's finest photographs of the Milky Way have, however, been made with an ordinary landscape camera strapped upon a telescope provided with clockwork for following the motion of the heavens.

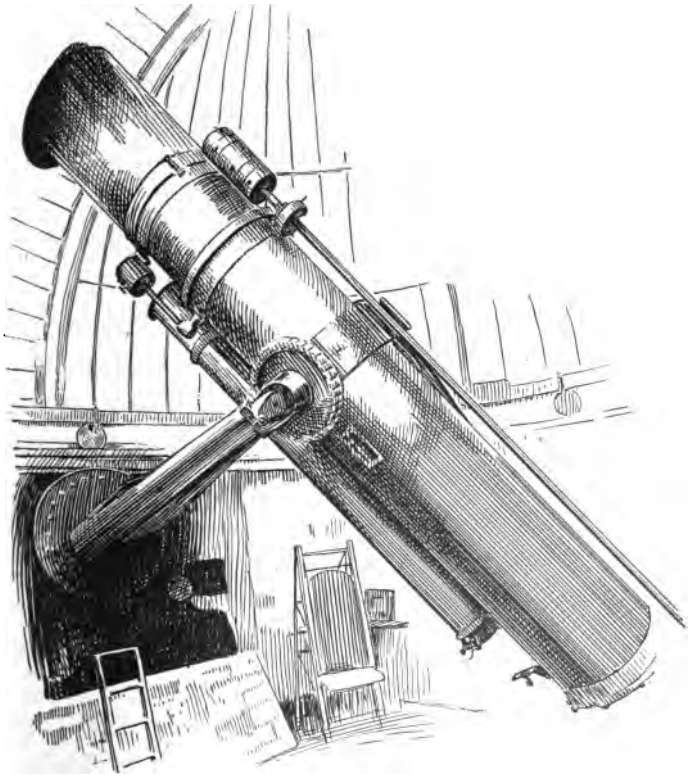
The field of view of these doublet instruments is often from five to fifteen degrees in diameter. It is with such lenses that the asteroid hunters generally work at present, using object glasses of

from six to twelve inches' aperture. The instrument is mounted like a telescope, with clockwork, and when pointed at the heavens it follows the stars accurately for the hour or two during which the exposure continues. When the plate is developed the negative shows the stars as round black dots; but if a planet is in the field, it will have moved with reference to the stars, and its image will be an elongated "streak," which is easily recognizable.

The largest and most powerful instrument of this class is the Bruce telescope, named for the late Miss Bruce of New York, who supplied the fifty thousand dollars which paid for its construction. It has a doublet object glass two feet in diameter with a focal length of eleven feet. It belongs to the observatory of Harvard University, but at present is mounted at Arequipa, Peru. Still another form of instrument is now under consideration by Professor Pickering, — a telescope of great focal length, say one or two hundred feet.

Thus far we have described only instruments designed to make pictures of objects in the heavens; but this is by no means the only use of

astronomical photography. Its most important application, perhaps, is in the study of spectra.



The Bruce Telescope

Excepting the sun and moon, the heavenly bodies are for the most part so faint that the eye can

accomplish very little in this line of work, even with the help of the largest telescopes. But the faithful record of photography obtained by the aid of the "spectrograph" and the "objective prism" enables the astronomer to work wonders in this field.

I have little space left in which to speak of the results already reached by celestial photography. First, perhaps, in order of importance should be mentioned the great star chart of the heavens, now nearly completed, by the coöperation of fourteen or fifteen observatories during the last twelve years. It will consist of about twenty thousand negatives, each about eight inches square, made with object glasses of fourteen inches diameter and eleven feet focus. The negatives will contain at least twenty million stars, and from them, by careful measurement, a catalogue is being formed of the positions of all the stars, two or three million in number, that can be seen with a telescope of twelve or fifteen inches.

In the same connection comes the discovery of more than two hundred new asteroids during the past twelve years; including among them — whether properly or not is perhaps doubtful — the little Eros, which is so interesting because at

times it comes nearer to us than any other body except the moon, and will therefore in time give us our most accurate determination of the scale of the solar system.

To photography we also owe a considerable number of recent measures of the parallax and distance of stars. Nor must we pass unnoticed the thousands of photographs of the transit of Venus in 1874 and 1882, although for reasons not yet entirely clear they failed to give the accuracy expected. New methods of great promise have been begun and are developing, by which photography is to be utilized in the routine observations by which time, latitude, and so forth, are determined with the meridian circle and kindred instruments.

In the line of purely astrophysical results we have the important series of solar photographs made daily at Greenwich, Mauritius, and Dehra Dun in India, which give us an almost continuous record of the sun's surface for the past fifteen or twenty years. Then there are the large-scale photographs of Janssen and others, which have thrown great light on the details of sun spots and the structure of the photosphere; also the numerous photographs of the corona during solar eclipses

—none so perfect and interesting as those obtained in India in January, 1898.

Photography has also added immensely to our knowledge of variable stars. It continually happens that the comparison of two negatives of any given region, made at different dates, shows changes in the brightness of some of the stars. Subsequent photographs soon determine the character and period of the variation. Mrs. Fleming, who has charge of such work at Cambridge, has already since 1890 detected more than a hundred such cases, among them four so-called "new stars."

Still more remarkable is the discovery in 1893 of great numbers of variable stars in certain star clusters where such a state of intense activity prevails that in the course of only an hour or two a dozen stars will vanish, and as many others become conspicuous. Most of the changes are found to be periodic, recurring regularly at intervals, usually of a day or two.

But the most wonderful revelations of photography have been in the study of nebulæ and comets, due mainly to the fact already stated, that their light is largely composed of rays which are invisible but vigorously active on the sensitive

plate. Stars, like those in the Pleiades, which in the telescope are seen as mere points of light, on the photograph veil themselves in shining robes of filmy mist. Nebulæ, hitherto regarded as almost structureless, reveal themselves as cloudy globes with whirling rings around them, or spiral whirlpools studded here and there with infant stars. A comet, tailless to the telescopic observer, is followed on the plate by a long train of luminous streams and filaments strangely tangled and intertwined.

It is in alliance with the spectroscope, however, that photography has been most effective in extending the dominion of astronomy. The eye alone cannot go very far in dealing with the spectra of the stars and nebulæ, because of their faintness; and even in the solar spectrum there are regions which are beyond its reach; to say nothing of such occasions as eclipses, when a photographic record of the spectrum, made in an instant but permanent, far surpasses in value any possible visual observation.

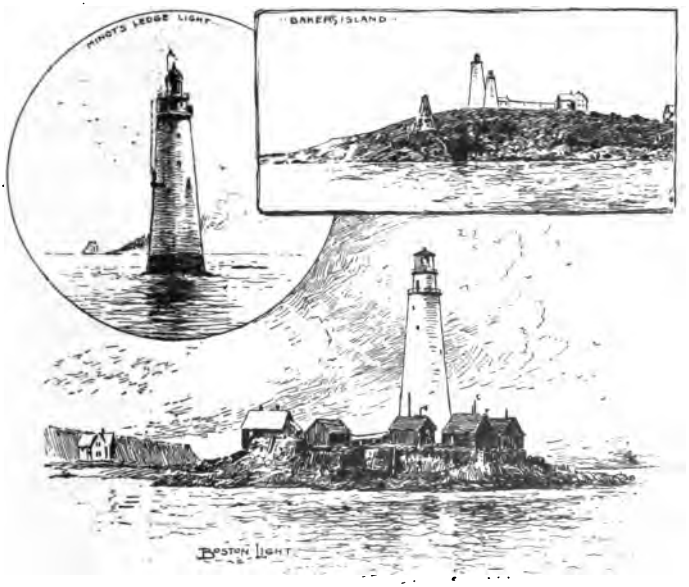
During the last ten years photographic spectroscopy has already given us classified catalogues of the spectra of more than ten thousand stars.

It has determined the rate at which all the brighter stars are approaching or receding, and so has determined approximately the speed with which our system is flying through space,—about eleven miles a second. One of the most interesting of all its results is the discovery of "spectroscopic binaries," pairs of stars so near each other that no telescope yet dreamed of could possibly show them as double, but moving with such speed that the lines in their spectra shift back and forth, or double and undouble, at regular intervals, and so reveal their real character. About sixty are already known, and in the case of one of them, an apparently little star in the southern hemisphere, the relative velocity is almost three hundred and fifty miles a second! And the united mass of the pair is seventy-seven times greater than that of the sun.

C. A. YOUNG.

THE LIGHTING OF OUR COAST

It is supposed that beacon fires were burned at several points along our coast, in early days of



commerce, to warn and to guide mariners who chanced to approach a harbor after nightfall; but the only beacon known to have been a "public

charge" from the first was that which was established soon after the settlement of Boston at Point Allerton, at the entrance to Boston Harbor.

"Fier-bales of pitch and ocum," the old record says, were burned there in a sort of iron basket swung from the end of a tall pole. Possibly a bonfire at Little Brewster Island, just across the ship channel from Point Allerton, also served at one time to guide vessels into the harbor.

Valuable as open beacons were in the absence of anything better, it became necessary as commerce increased to replace them by lights which would burn steadily and surely whatever the weather might be. As early as 1716 a lighthouse, the first on the continent, was built on Little Brewster Island and named the "Boston Light." The lantern at the top of this tower gave forth a feeble gleam at night from tallow candles.

Little was known then of illuminants suitable for lighthouse purposes, but within a few years candles gave place to lamps, which were, however, but a trifle brighter and more steady than the candles. Some one experimented with reflectors of primitive forms, till a combination consisting of a metal reflector placed behind a lamp of the

"Argand fountain" type was, in 1812, thought worth adopting in this country for lighthouse use.

The reflector proved to be but a poor help to the lamp, and a "bull's-eye" of glass, set up before the flame to make the light still brighter, was almost an obstruction in itself. Reflectors led to revolving lights, which were a desirable addition to the small list of "characteristics" distinguishing one light from another.

During the eighteenth century lights were established at Cape Ann, Plymouth, Gay Head, Nantucket, in several places on the coast of Maine, and on the coast to the southward; but all these had but two distinguishing marks, — they were fixed white, either double or single.

Lamps and reflectors were improved greatly during the early part of the nineteenth century, and made at last to furnish a light so brilliant that it held its own for some time in this country, even after the "Fresnel lenticular apparatus" had been approved abroad.

The problem of lighthouse engineers had long been to find a way of directing the rays from a tower lamp toward the horizon, where they are needed most, instead of leaving them to light up

the sky and large spaces of unused seaway. As rays of light from a luminous point are given forth in all directions in straight lines, a simple unaided burner in a lighthouse tower provides only one little pencil of rays for any one ship on the horizon. All the other rays are sent elsewhere — many of them toward the sky.

The force of a light diminishes as the square of the distance. A very bright but unaided light is not seen at the horizon as soon as the curvature of the earth alone will allow; it defines itself very slowly to the seaman coming toward it. But if to the single pencil of rays, falling from the focus toward a point on the horizon, all the wasted rays could be added, a small light would become brilliant at once.

If you think of the sky as an inverted bowl with its rim for horizon, and with a lighthouse beneath, proportions of course being disregarded, you have a picture like the diagram in Fig. 1. The arc from A to B and the space from D to C need no rays from the lamp. It was necessary to devise a means of bending all the rays that would strike

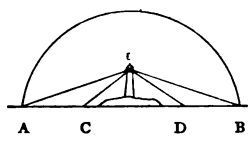


FIG. 1

on those two spaces so as to add them to those falling between A and C, and D and B.

This was done on the principle of the plano-convex lens, applied and proved by a Frenchman named Fresnel, after whom the "lenticular apparatus," now used all over the world, was named. By means of this apparatus it has been possible to show a light of one hundred and fifty-nine thousand candle power in the new Eddystone tower, where, two hundred years ago, the twinkle from twenty-four tallow candles was the pride of all England.

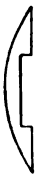


FIG. 2

For many reasons it is not practicable to employ a solid lens large enough to serve lighthouse purposes. It was found that a cut lens would serve precisely the same purpose. Rays of light passing from a denser to a rarer medium are refracted — bent out of their path — only at the points where the change takes place, showing that "only the skin" of the lens, as some one says, is its working part.

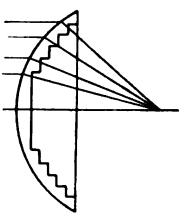


FIG. 3

Figs. 2, 3, and 4 show the principle of cutting down a lens. A front view of Fig. 4 would show

FIG. 4

a lens-shaped center, surrounded by curved ridges of glass. A series of lenses like this, several feet high, built up by means of strong metal framework into a cage round a lamp in the center, controls and bends into parallel rays a large portion of all the rays passing through it.

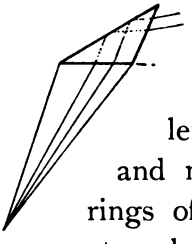


FIG. 5

Still other rays, straying above and below the lens, are "caught," and made to work, by rings of prisms arranged at such an angle with the rays as to send them forth in parallel lines (Figs. 5 and 6). The prisms are made in small pieces, built up into the form of a beehive above the lamp, and, like the lenses, are firmly cemented into metal frames (Fig. 7).

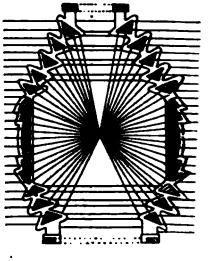


FIG. 6

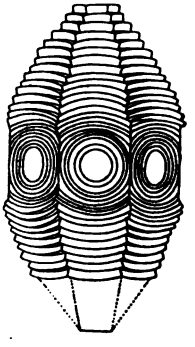


FIG. 7

Looking down at night on a lens like this, lighted, one would see bands of brilliant light streaming forth across the sea, one from

each "eye" of the glass dome, with wide, dark spaces between, dangerous to the ship that might chance to sail up without seeing the band on each side. But if the whole structure were made to revolve, the result would be no longer brilliant and misleading, but a flashing light, proved now to be of the very first value to mariners.

It was only a step from this principle to the next one, a lens for a fixed light. A lens of straight lines giving the same vertical section in every part of a panel was devised, with the reflecting prisms, also, arranged in straight instead of curved rings.

A "beehive" built up of alternating curved and straight sections, or panels, and made to turn, will show a fixed light while one of the straight portions is passing before the eye, and a flash while the curved portion is passing. A red chimney on the lamp inside, or a red pane of glass on one kind of panel, produces several "characteristics,"—the "fixed white with a white flash"; "fixed red with a red flash"; "fixed white with a red flash"; "fixed red with a white flash." A "group flashing" light is made by alternating a number of curved panels with a straight one,

or with a dark space, giving "fixed red or white, varied by red or white flashes in groups," or the most modern of all, the famous counting light, like Minot's Light, that tells off a number by flashes.

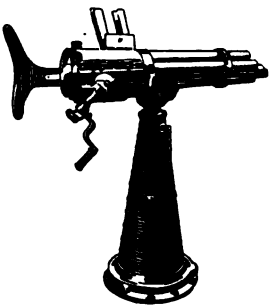
The Fresnel illuminating apparatus is divided into six orders, three superior and three inferior, ranked according to their size and the size of the lamp used.

The first order, the largest, consists of a glass "beehive" about ten feet high, large enough for several men to stand up in, and having in the center a stationary lamp with a burner carrying five concentric wicks. The first-order lights occur only at prominent seacoast sites, where they are intended to be visible to the mariner at twenty miles' distance across open sea.

LOUISE LYNDON SIBLEY.

MODERN GREAT GUNS

THE guns in use in the United States Navy, before the adoption of the breech-loading system, were muzzle-loading smoothbores and rifles, called after their inventors, Dahlgren and Parrott, respectively.

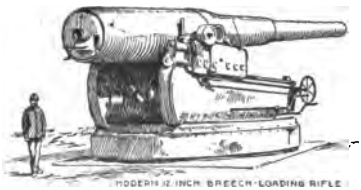


These guns were made of cast iron, the Dahlgrens being cast in a solid piece and then bored and turned down in a lathe. The heart of the casting contained the inferior metal, which was removed by the boring tool. The Parrott rifles were cast hollow, a stream of running water on the inside causing a uniform rate of cooling of the outside and the bore.

As these guns were muzzle-loaders, it was of course necessary that the projectiles should be a little less in diameter than the bore of the gun, so that the shot or shell could be rammed down

on the powder charge quickly and easily, and also so that a space might be left above the shell for the flame of explosion to pass in order to ignite the fuse, which was in the front of the shell.

This looseness of fit, as it might be termed, caused a lack of precision in firing, for in the smoothbores the round shot would bound or "ballot" along the bore, while the Parrott rifle shells would often turn over end for end or "tumble" in their flight. The consequence was that no amount of care would insure a good shot.



MODERN 12-INCH BREECH-LOADING RIFLE

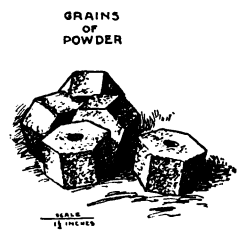
So a breech-loading gun came to be a necessity; that is, a gun which should do away with the old slow and dangerous methods of loading, and which would also take into its bore a closely fitting projectile that would go straight to the point aimed at.

The idea is not altogether a modern one, for when Cortes invaded Mexico he carried with him small bronze breechloaders, the charge of powder being contained in a hollowed recess of the breech plug. One of these pieces is preserved as a relic

at the Naval Academy at Annapolis, and in its design suggests some of the features of the famous Krupp breechloader which is to-day the leading weapon of Europe.

The favorite breech-closing mechanism is a screw plug, whose threads increase in twist so that the last turn of the handle pushes the screw threads firmly against the threads of the breech. Leakage of gas from the combustion of the powder is provided for by a gas-check pad, which is expanded against the surface of the chamber of the gun by the force of the explosion.

The shell fits much more closely than in the muzzle-loader, and a rotating motion is given it by the expansion into the grooves of the gun of a soft metal band around the base of the projectile.



Breech-loading rifles are from thirty to forty calibers in length. The powder first designed and used in these guns was in large grains, brown in color from a peculiar charcoal that is used, each grain resembling in shape a six-sided iron nut. This powder is slow burning as compared with the quick-acting,

fine-grained powder of other days. The reason for this is the desirability of avoiding the sudden shock and strain on the interior of the gun consequent on quick combustion of the powder. So the gun is made very long, and time is given for all the powder to be consumed before the projectile passes the muzzle face.

The hexagonal shape is given to the powder grain because that form allows of the closest stowage in the cartridge bags. Each grain has a hole through the center to allow the free passage of the flame and to facilitate the burning.

A peculiar feature of the powder is that it is so hard pressed that it can with difficulty be lighted with a match, requiring for its explosion the quick, penetrating flame of a fulminate primer. At present, smokeless powder is gradually replacing the brown powder for use in all guns, large and small, including rifles and revolvers.

The great guns for the navy of the United States are made at the gun foundry at the Washington Navy Yard, from forgings furnished by the principal steel workers of the country. Unlike the older guns, the Parrotts and the Dahlgrens, the breech-loading rifles of to-day are "built up," as

the term is, of different parts, the foundation, or tube, having shrunken over it cylinders, or jackets, which give the necessary thickness and strength over the chamber where the combustion of the powder takes place. These jackets are put over the tube while hot, and contract on cooling, holding the tube tightly in their grasp.

The advantage of this building up over the old system of casting solid is that greater certainty in obtaining metal free from defects is insured by combining parts of small thickness.

The principal guns in use are the four-inch, five-inch, six-inch, eight-inch, ten-inch, twelve-inch, and thirteen-inch, and they form the main battery of our new cruisers. The four-inch gun weighs thirty-four hundred pounds, and throws a shell of thirty-three pounds, with thirteen pounds of powder; the thirteen-inch weighs one hundred and thirty-six thousand pounds, or nearly sixty-one tons. Its shell weighs eleven hundred pounds, and the charge of powder is about five hundred and fifty pounds.

At the muzzle the thirteen-inch shell will penetrate twenty-seven inches of steel, and at twenty-five hundred yards, or a mile and a half, it will go

through twenty-two inches of the same metal, the average velocity of the shell being nineteen hundred feet a second.

The powder charge for the larger guns, mounted in the turrets of our monitors and battle ships, is in two bags, one half the charge in each, and is brought to the breech of the gun from the ammunition room by an electrical ammunition hoist. The shell is brought up by the same hoist, and when in position is pushed to its place in the chamber of the bore by a hydraulic rammer fixed directly in the rear of the gun.

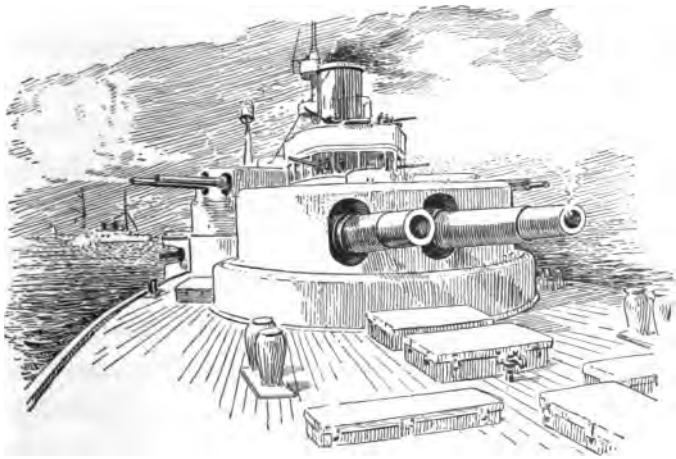
GATLING GUN IN ACTION

The secondary battery of ships of war consists of Gatlings, Hotchkiss rapid-fire guns, and revolving cannon, firing projectiles of varying size, from the leaden musket ball up to a steel shell of six pounds. These all carry fixed ammunition; that is, the powder is contained in a metal case, in the front of which the projectile is fixed, like the familiar cartridges of a pocket revolver.

These guns have great penetration and long range, and from their position on the bulwarks

and bridges of men-of-war, and in the fighting tops of military masts, can pour in on the advancing boats of an enemy a wholesale and murderous fire.

Modern guns are controlled wholly by mechanical appliances, and to the uninitiated these may seem very complicated and suggestive of easy



Ready for Action

derangement at a critical moment. A valve might give out, a rod break, or some gearing be destroyed by a shot, and the gun rendered wholly useless. This is all true, but the advantages are on the side of mechanical handling of guns over the old-time training with tackles and handspikes.

Victory in action will go to that side whose fire is most quickly and accurately delivered; and when it is borne in mind that in these days of huge projectiles and great penetrating power one shot judiciously aimed may gain the victory, and work perhaps the destruction of the mightiest ironclad, it will be seen that the advantages will lie with the side that has at its command the most improved guns and appliances, and the greatest skill in managing and handling them.

The range of modern rifles is so great that in an action between ships of war no time can safely be lost in delivering telling blows. The thirteen-inch gun, at extreme elevation, — about forty-two degrees, — can send its shell to a distance of ten or twelve miles, so that a ship might easily lie almost out of sight of a beleaguered town and pour in its fire with impunity.

In determining the distance of an object to be fired at, an ingenious device has recently been invented by Lieutenant Fiske of the United States Navy. In the Fiske range finder, as in so many modern inventions, electricity is called in to assist, and it does its work quietly and with precision. Two observers, one at the bow and one at the

stern, direct telescopes at the target; the telescope standards are connected by wires with a dial in the conning tower, and an automatic signal works a pointer on the dial, which shows the captain the distance of the target in yards. The captain transmits this information to the officers in charge of the different batteries, who lay their guns accordingly.

The proving, or testing, of naval guns, their powder and projectiles, before being issued for service, is conducted at the government proving ground at Indian Head, Maryland. Before and after firing, the bore is carefully gauged and the measurements compared to see if any enlargement has resulted from the firing.

Then the guns are ranged by being fired at different elevations, and by measuring the distances traveled by the shell before striking.

The velocity of the shell is measured by firing through a series of targets across which are strung wires electrically connected with a chronograph in rear of the firing station. These targets are placed at certain intervals apart, the first one being directly at the muzzle. As the wires are successively broken by the passing shell, a record is

automatically made of the time intervals on the chronograph, and the velocity determined for each distance as measured by the targets. In the larger guns the velocity at the muzzle must be two thousand feet per second with a full charge of powder.

The principal test given the powder is the measurement of the pressure it exerts against the bore of the gun. In the thirteen-inch breechloader the limit of pressure is fifteen tons to the square inch, any higher pressure being considered dangerous to the gun itself, and indicative of an inferior grade of powder that may be liable to deterioration and spontaneous combustion.

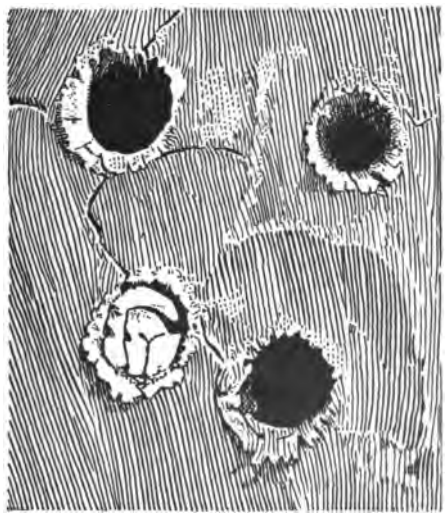
A TEN-INCH SHELL AFTER PASSING THROUGH TRIAL ARMOR PLATE.

To measure the pressure, a gauge is fixed in the front end of the breech plug, next the powder, and the amount of compression of a small copper cylinder by the explosion of the powder charge is noted. The degree of compression, compared with the original thickness of the cylinder and based on previous experiments with known pressures, determines the exerted force in tons.

The shell, which is of hardened steel, must, generally speaking, penetrate a steel plate of one

and one-fourth calibers without injury to itself, at a range of fifteen hundred yards, with full powder charge.

At the proving grounds are also tested the sample armor plates submitted by the contractors. These plates are set up against a very heavy oak background, behind which is a large butt, or mound of earth. The immense force with which the shot are hurled against the plates can be judged from a glance at the marks of the projectile upon the target in the accompanying illustration.



Target

The target is usually about four hundred feet from the gun, and two shots are used in the test, one fired at a low velocity, the other at a high

velocity. The plate, to pass satisfactorily, must not be cracked through or from edge to edge by the first shot. With the high velocity the shell must not penetrate the plate and the three feet of oak backing, either whole or in fragments, nor must any fragment get through. The most satisfactory plate so far experimented with is one which has a hardened surface, the rest being of softer steel, which, in case of cracking or injury to the face, serves to hold the plate together and to check the extension of the injury.

The race between projectiles and armor is still going on, and which will eventually win is a matter of mere conjecture. Improved armor is closely followed by the invention of hardened projectiles, and these in turn fail to produce any impression on some new type of plate.

The tendency of the age is toward perfecting the implements of warfare, and the final result may happily be that as nations grow in military knowledge and power there will be an increasing hesitation to engage in conflicts, because of a wholesome fear of the tremendous power for destruction that an enemy may possess.

JOHN B. BRIGGS.

SUBMARINE BOATS

THE first submarine craft of which we have any definite knowledge was built by Cornelius Van Drebbell, a Hollander, who made some curious experiments under the Thames in 1624 with a

Torpedo-Boat Destroyer at Work

diving boat that was propelled by a dozen oars and carried as many passengers. His secret perished with him, but it is certain that he knew how to purify the air in his vessel, to dive and

come again to the surface at pleasure, and to propel the boat with fair speed either on the surface or below the water.

American inventors were busy with the idea very early in our history. Bushnell of Connecticut in 1775 constructed a boat which Washington described in a letter to Jefferson as "a machine so contrived as to carry the inventor under water at any depth he chose, and for a considerable time and distance, with an appendage charged with powder, which he could fasten to a ship and give fire to it in time sufficient for his returning, and by means thereof destroy it."

The external shape of this boat bore some resemblance to two upper tortoise shells of equal size joined together, and its interior was of sufficient extent to carry one operator and to afford pure air for about thirty minutes' submersion. On the outer shell over the rudder a large powder magazine was transported. This could be exploded by clockwork at any time within twelve hours. The magazine was secured in place by a wooden screw, with which it was connected by a stout line. When the operator reached the keel of the enemy's ship he was

expected to force this screw into the plank, then to detach the magazine, and hurry his boat out of harm's way.

After numerous experiments in Long Island Sound, Bushnell made an attempt to destroy the British war ship "Eagle," then lying off Governors Island in the harbor of New York. When he reached a position under the ship, he tried to attach his magazine, but the screw struck a bar of iron. In seeking another place he drifted away from the ship and was unable to find it again. Determined to test the explosive value of his invention, he cast off his mine and "an hour afterward," writes Holland, "the magazine exploded some distance from the ship, throwing up a huge column of water, greatly to the consternation of those on board, who were unable to ascertain the cause of so singular a phenomenon."

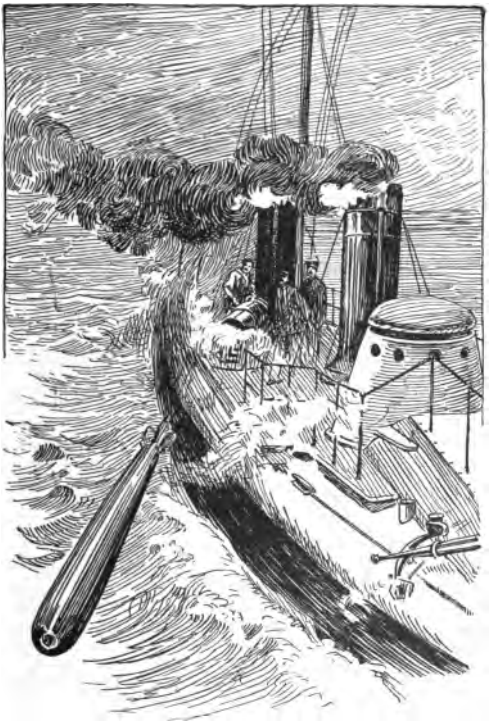
Robert Fulton borrowed Bushnell's idea, and in 1801 experimented successfully with a diving boat that was propelled by two parallel screws and ascended and descended by means of vertical screws. He experimented with it at Rouen, Havre, and Brest, and, being satisfied with the correctness of his theory, went to Paris and built

one on a new model. With this boat, named the "Nautilus," he made some interesting experiments in the Seine; and in 1801, at Brest, he remained in it under the water for three hours, moving in all directions at will. In August of that year he carried a cubic foot of compressed air, which enabled him to keep submerged for four and one-half hours. But as his invention received no serious attention abroad or at home, it was not further developed by him.

In 1851 a shoemaker named Phillips launched in Lake Michigan a cigar-shaped boat, forty feet in length and four feet in diameter. This machine was very crude, but in the course of a few years he had so far perfected his arrangement for purifying the air that on one occasion he took his wife and children and spent a whole day in exploring the bottom of the lake. He is said to have carried a six-pounder smoothbore gun in the bow, and to have fired shots from it into hulks anchored for the purpose. Later it is recorded of Phillips that he made a descent in Lake Erie, near Buffalo, and never reappeared.

Many other experiments were made both here and abroad, the most successful being those of

a Russian mechanic, who, in 1855, perfected a diving boat in which he remained under water



Discharging a Torpedo

for eight hours. The greatest impetus given to the development of the type was the result of the part played by submarine craft in the Civil War.

In 1864 the most notable of these, a boat named the "David," sank the United States ship "Housatonic" off Charleston harbor.

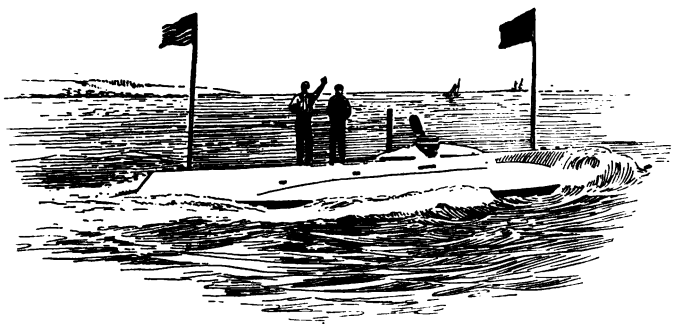
This submarine boat was built of boiler plates and shaped like a cigar and could be propelled by eight men at a speed of about four knots an hour. When advancing to attack, the top was at the level of the water. Three trial trips were made, but each time she sank and failed to rise, and in each instance her crew were suffocated before they could be rescued. On the fourth trial she ran safely out of the harbor; but, although successful in blowing up the "Housatonic," she was drawn into the vortex of the sinking ship, and her gallant crew perished.

Up to the end of the Civil War the underlying theory demanded a boat that could approach a ship on the surface of the water until almost within the radius of discovery. Its duty then was to sink, place a torpedo under the ship, and after moving to a safe distance, to explode the mine.

But as modern warfare developed, ships could no longer anchor during bombardment, nor as a rule could they attempt to force channels and

make a direct attack by night or day, because of the mine fields and the watchfulness of the vedettes and torpedo boats. Blockades, it was found, had to be maintained at distances impossible in the sail period, and therefore a new type of submarine boat became necessary.

The construction has to be water-tight and strong enough to resist great pressure; it has to



The "Holland"

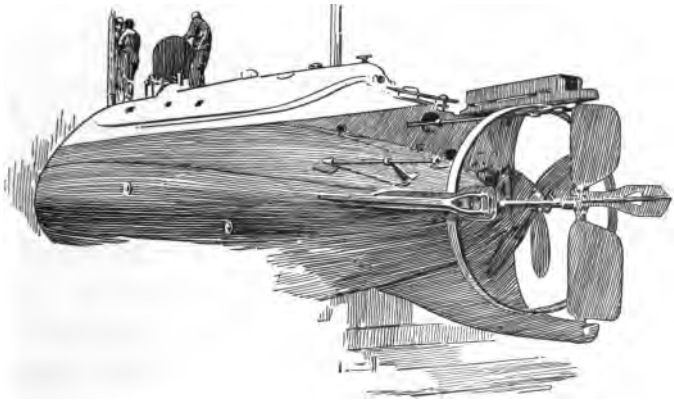
be supplied with sufficient air; and its stability has to be determined carefully, for the underwater conditions are very different from those existing on the surface. Other qualities deemed essential are good engine power; a capacity to travel relatively long distances; rapid diving power to avoid gun attack; maneuvering power

to descend or ascend quickly; dimensions not too great to forbid operations in shallow water, and a possibility of delivering attacks from a distance. A battery of small but good guns is considered of value, and, most important of all, pilots must be able, when submerged, to scan the horizon and to steer a true course without being discovered by the enemy.

Many of these qualities have been secured, but the one which yet seems almost unrealizable is the power to tell, with accuracy, the direction in which the boat is going after it has sunk beneath the surface.

Mr. Holland, the inventor of the best diving boat so far tried in this country, declares that in all save a few of the most modern types the intention of the designers is to steer the vessel by sight while under water. Formerly he held the opinion that steering by sight while submerged was quite practicable, and he thought it would be a simple matter to find the most vulnerable point in the bottom of a ship, to which the torpedo could be attached. A few submerged runs soon convinced him that some guide other than vision is needed to direct a boat's movements.

"I had no suspicion," Mr. Holland states, "that my boat could not be steered perfectly, until I had made about half a dozen preliminary dives to adjust the automatic apparatus. Having become doubtful of the reliability of the compass, I had it carefully compensated, and then



Stern View of the "Holland"

made a trial submerged run in New York harbor, heading the vessel toward a point which I knew was about twelve minutes' run distant. The boat dived at an inclination of fifteen degrees; and it was noticed that when she again reached a horizontal position the compass needle had swung around a complete circle, and vibrated a good deal before

coming to rest. The boat was then discovered to be about ninety degrees off her course.

"It was steered again in the proper direction, and then inclined upward at a sharp angle to find whether the action of the compass would be as erratic while rising as while running downward. One end of the needle dipped to the bottom when beginning the ascent, and remained there during the rise. When the boat approached a horizontal position, a few feet below the surface, the needle swung around as violently as it had done during the boat's descent, and then came to rest again at a point that indicated the boat to be far off the true course.

"As it appeared quite clear that the run was not made in the direction intended, and that about one mile must have been covered from the start, ten minutes having already passed, the boat was brought to the surface of the water just in time to prevent her from running on rocks that lay about twenty yards straight ahead and sixty yards down from the starting point. The boat had started to run over one mile upstream, and the mile run ended sixty yards downstream, with the boat heading exactly opposite to her original direction."

It is this lack of power to direct the course accurately that renders doubtful the possibility of complete success with a submarine boat. To attain this, various devices have been used, such, for example, as the *camera lucida*, which is carried in a tube projecting above the surface; but when this instrument is used to assist in determining the direction, it must be withdrawn before the enemy can locate and destroy the vessel. Some modern submarine boats bring their turrets to the surface for a short time to enable the pilot to lay a course; others claim to own secret processes; but no known method has so far proved trustworthy.

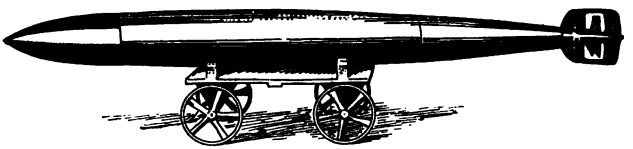
Nordenfeldt made many experiments in 1885 with a cigar-shaped steel boat. Steam was the motive power, and by an ingenious arrangement the necessary pressure could be retained during submersion after the combustion in the boiler had ceased. This device was a large reservoir, or hot-water cistern, placed in the fore part of the boat and connected with the boiler. Before reaching this auxiliary cistern the steam passed through a number of tubes, thus gradually raising the temperature until the boiler and reservoir

pressure were the same. Ordinary combustion was carried on while at the surface, but when the time came to dive, the furnace doors were closed, the combustion was stopped, and the steam given off by the hot water in the boiler and cistern was used with such efficiency that the engines could be kept going for several hours. The boat dived by means of vertically acting screws, a few revolutions of which would send her under water, while the stoppage of this motion would bring her to the surface.

The French have been particularly active in their experiments with submarine boats. In 1863 Admiral Bourgeois made many trials with a boat called "Le Plongeur," and achieved such success that he is said to have received an order for three hundred boats from the Russian government, fifty of which were delivered. Spain was equally active, notably with the Peral type, but none of these, except perhaps the "Goubet," excited so much public interest as the "Gustav Zédé."

The first submarine boat built by Zédé, the "Gymnote," was laid down at Toulon in 1886. To all intents and purposes she was nothing more than a large Whitehead torpedo, of the following

dimensions: length, fifty-six feet; diameter, five and nine-tenths feet; displacement, about thirty tons. Horizontal rudders made her dive or rise to the surface. She was driven by an electric motor of fifty-five horse power, the current of which was supplied by a storage battery sufficient in capacity to run the vessel for four or five hours. The speed was about seven knots when submerged and nearly nine knots on the surface.

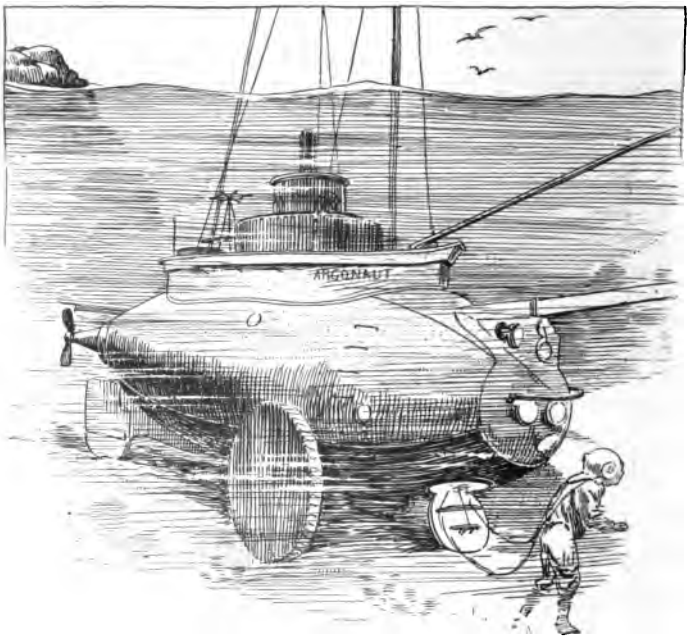


A Whitehead Torpedo

Water-tight compartments placed fore and aft secured the required buoyancy, and the air necessary for the respiration of the crew of four or five men when submerged was stored in reservoirs. Detachable ballast which could be released from the interior of the boat was carried along the keel.

The trials of this boat were so satisfactory that Zédé determined in 1890 to build one of a similar type, but of larger dimensions. This vessel, originally named the "Sirène," is now the famous

"Gustav Zédé." Since that date the development has been marked. Nearly all the navies are experimenting with the type, and even Great



The "Argonaut"

Britain is participating in the race for supremacy. The French are enthusiastic experimenters, and they have nearly forty of the type afloat or under construction. The United States has seven of

the Holland model, and intends to test these to a finality — so far as peace permits — before embarking largely in this new sea of endeavor.

What the material effect may be it is too early to predict; but the moral effect of submarines upon a blockading or a bombarding fleet is surely very great. It aids the defense greatly by forcing the attack to keep long distances from the point ashore where a blow must be delivered, — notably at night, — and it is probable that here and not in offense work will be found its true mission.

J. D. Jerrold Kelley.

HOW WAR SHIPS ARE BUILT

EVER since governments began to maintain naval establishments, government experts have been studying the requisites of naval vessels. It is evident that a man-of-war should be strong, so as to withstand not only the storms of the ocean but the shock of battle; that she should be large, so as to carry a large fighting force and powerful weapons; that she should be fast, so as to overtake an enemy or to run away from one she could not encounter.

Experience, however, soon taught that the strongest and best armed ship could not also be the fastest, and therefore ships came to be built of different classes, some for lookout ships, some to prey upon an enemy's commerce, and some to fight in the line of battle. In the days of sailing vessels, a ship carrying not less than seventy-four guns was called a "line of battle ship."

In the early part of this century steam power began to be applied to merchant ships and, of

course, as naval vessels should be of the very best, this new force was soon utilized on board naval ships not only for propelling, but for many other purposes. A large modern man-of-war has on board engines to work the rudder, to hoist the anchors, to turn the turrets, to hoist the ammunition, to distill water, to manufacture ice, to generate electricity for lighting the ship, to work the pumps, and to wash ship, etc., etc. The "New York" has on board sixty-seven engines.

The ship itself is of steel and usually has double bottoms. These serve two purposes: first, the ship's inner bottom will keep her from sinking in case of an accident to the outside skin; and second, the interstices between the two bottoms may be filled with water or emptied as the trim of the vessel may require.

The lower part of the ship is also divided into many water-tight compartments, made by bulkheads or partitions running lengthwise and crosswise. One or more of the compartments thus made might get filled with water, and still the ship would float.

There must also be quarters for the officers and men, accommodations for the sick, places to stow

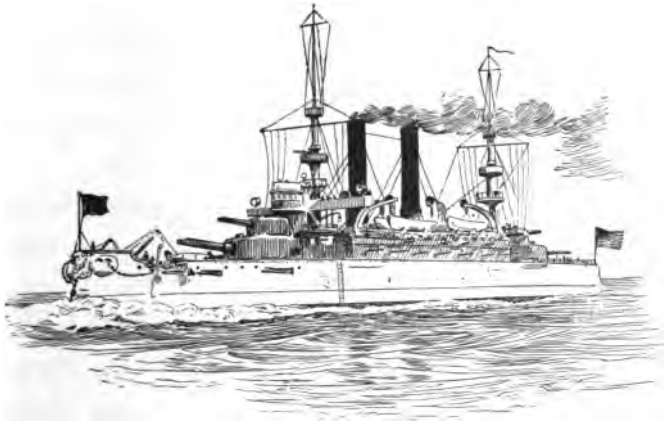
away coal and ammunition and provisions and ship stores of all kinds.

Let the reader bear in mind all these things; let him also remember that a ship must be so constructed and all the weights so distributed that the vessel when in the water must be practically on an even keel; then he will begin to understand how difficult it is to design a modern naval vessel correctly.

The art of shipbuilding has become a science, or, to put it differently, ships are now designed by men thoroughly educated in shipbuilding. All the lines, proportions, and weights of a vessel about to be constructed are calculated on the most exact and scientific principles. The weight and position of every plate, angle, bolt, engine, gun, ammunition chamber, etc., and its precise position in, or upon, the vessel are estimated beforehand.

When the ship is building, all its several parts are weighed before being put into it, and of course the utmost care is exercised to see that all these are as nearly as may be of the exact weights and dimensions prescribed. If they are, the ship will sit in the water precisely as intended, provided of course the designers' calculations are correct.

The Navy Department has four bureaus that are concerned in the building and equipment of a ship. The Bureau of Construction and Repair is responsible for the general designs of a vessel, and especially for the hull and fittings; the Bureau of Steam Engineering for the engines



A Modern War Ship

and boilers; the Bureau of Ordnance for the armor and armament — armament means guns and ammunition; and the Bureau of Equipment looks after anchors, chains, electric lighting, and various other things upon the ship.

The officers of the Bureau of Construction and Repair are called constructors and assistant

constructors, and their whole time is occupied in the building and repairing of ships.

The officers of the Bureau of Steam Engineering are called engineers. Highly educated in their profession, they attend to all engines on board ships, and the most eminent among them are chosen for service in the bureau where engines are designed.

The officers of the Bureaus of Ordnance and Equipment are line officers, selected because they have especially adapted themselves by their studies to the duties appertaining to these bureaus.

These several bureaus have all the information relating to their several duties that can be obtained, — books, periodicals, drawings, and plans of work done in other countries, — and the Bureau of Intelligence, through our naval attachés, keeps them constantly informed as to what is being done abroad.

Naval vessels are never built until Congress gives authority and makes an appropriation of money. The act of Congress usually specifies the general type and the approximate size, and limits the cost of the ship. It then becomes the duty of the Navy Department to prepare plans in accordance with the general requirements of

the act of Congress. Usually Congress has consulted with the Secretary as to the type of ships most needed before passing the act.

A few of our naval vessels are built in government navy yards, but they are mostly let out to contractors. When a vessel is authorized, as a

The "Massachusetts"

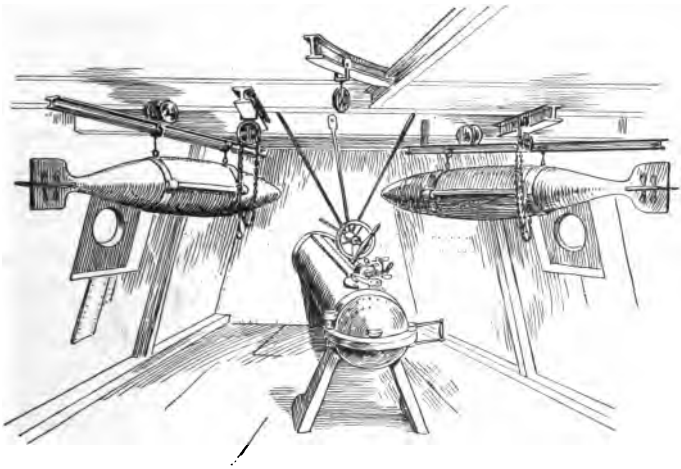
first step, the Secretary directs the Bureau of Construction and Repair to prepare one or more preliminary designs showing what can be done in accordance with the act of Congress. Sometimes he accompanies these instructions with other directions, as that the draught of the ship must not be more than a given number of feet.

In the preparation of preliminary plans exact work is not attempted, but in a few weeks the chief constructor presents to the Secretary one or more plans showing the general outlines and dimensions of the ship, roughly the weights assigned to the different objects, the guns carried, and all the general features and arrangements of the vessel.

The Secretary examines these plans and then submits them to a board of officers, and, aided by their report and advice, he makes up his mind as to the plan that is most desirable. Then the Bureau of Construction and Repair proceeds to the exact determination of the model, so-called, or the dimensions and shape of the vessel. This is the most important and at the same time the most difficult and delicate of all the work to be done.

The draught of water, as has been stated, has often been prescribed beforehand, having been fixed by considerations connected with the intended service of the vessel. Our battle ships should be able to get into our principal ports without difficulty, while a gunboat, especially if intended for service in Chinese rivers, must be of very light draught.

The beam — or width — of the ship is intimately connected with its draught, as upon the beam and draught and shape of the ship, taken together, depends very largely the stability of the vessel. All these and the weights must be so



Torpedo Room of a Battle Ship

adjusted to one another that the center of gravity shall not be too high; if it is, the ship will capsize. Neither must the center of gravity be too low; if it is, the ship will right herself too suddenly; that is, when she lurches to one side she will go back with such a jerk that she will not be a good gun platform. She must roll easily.

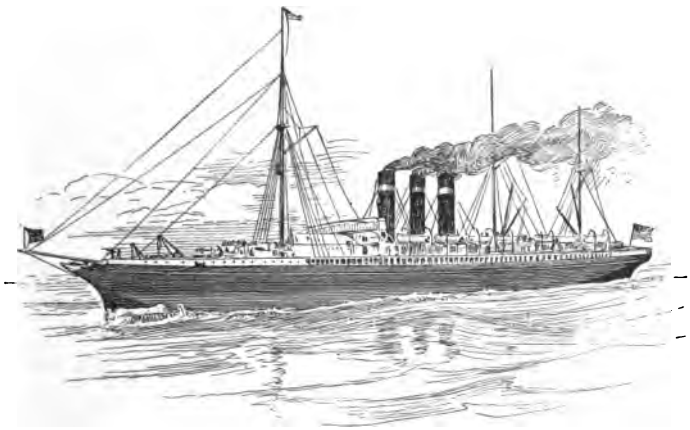
The center of gravity of the ship can of course never be ascertained until the weights and positions of the guns and gun mounts, ammunition, engines, chains, anchors, and everything else have been fully determined upon. The center of buoyancy must also be considered in connection with the center of gravity.

The center of buoyancy is the center of gravity of the volume of water displaced by the ship, and when the ship is afloat the center of buoyancy and the center of gravity of the ship must always be in a vertical line — one directly above the other. If the center of gravity is forward of the center of buoyancy, the ship will go down by the head, — that is, draw more water forward than aft, — and she would go down by the stern if the center of gravity were too far back.

To represent upon paper the contour or outside form of the intended ship numerous drawings are necessary. There must be a series of lines representing the intersections of (1) horizontal planes, (2) vertical planes across the ship, and (3) vertical planes running lengthwise with the ship. All these three sets of curves must agree exactly one with another.

The Bureau of Construction must also furnish not only the exact dimensions of every angle, bar, plate, and everything else going into the construction of the hull of the ship, but also plans showing all the interior arrangements of the vessel.

The Bureau of Steam Engineering must draw



The "Harvard"

plans showing the shape and dimensions of every part of every engine it designs.

The Bureau of Ordnance must furnish general dimensions and weights and plans of guns, gun mounts, and armor, and the Bureau of Equipment gives the weights and dimensions of the articles

it is to furnish. When all this is done the plans are complete.

Specifications are then drawn up and printed, to be furnished to builders or bidders. These describe in detail the manner and method of constructing the vessel in all its parts, giving thickness, size, quality, and strength of material, and minute directions as to the manner in which the work is to be done.

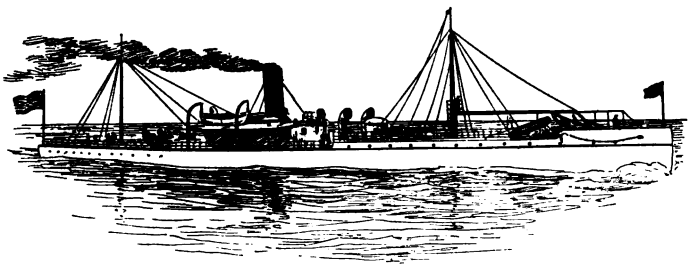
As soon as the department has prescribed the general features of a design, and given directions for the detail work above described to proceed, advertisements are issued — if the ship is to be let out by contract — informing shipbuilders that bids will be opened on a certain day for the construction of the vessel or vessels in question, and that the plans and specifications are subject to examination.

The shipbuilder never furnishes the armament. Great guns are exclusively assembled at the Washington Navy Yard. Some of the smaller guns are built there, and others are purchased from manufacturers.

Bidders are always notified that they can bid upon the government plans or upon plans of their

own, and they frequently bid upon the department plans with slight modifications.

When the day fixed upon arrives, the bids are all opened in the department by the Secretary, and the contract let to the lowest responsible bidder. The bidder is thereupon furnished with the plans and specifications, and to see that he complies with them, a naval constructor or



The Dynamite Gunboat "Vesuvius"

assistant constructor is stationed at his works, and this officer inspects and reports upon the work as it progresses.

An engineer officer is also detailed to supervise the work upon the engines. Other officers are stationed at the works of the steel makers, and they rigidly inspect and test all the plates, bars, angles, and everything else got out for the shipbuilder, rejecting all defective material.

The manner of testing armor plates is for the inspector to test the material of each plate for tensile strength, elongation per square inch, and elasticity. He then selects from a group of twelve or fifteen plates that one which appears to be the poorest, and sends it to the government proving ground at Indian Head, where it is fired at by great guns. If it stands the prescribed test, the group is accepted; if not, the group is rejected.

Payments for vessels under contract are made as the work progresses, but the government reserves until final completion of the vessel ten per cent of each installment to secure itself against loss, and also requires that the ship be kept insured for its benefit.

A shipbuilder first lays the keel of a vessel, taking great care to have it of correct shape and dimensions. The ship, as it gradually grows into shape upon the keel, rests upon "ways," a wooden structure sufficiently elevated to give workmen access to the bottom of the vessel, and always located near the edge of the water into which the vessel is to be launched.

The launch takes place after the hull and framework have been completed and is an interesting

occasion. Usually many guests are invited to witness it. A name for the ship has first been

A War Ship in Action

selected by the President or the Secretary, and some young lady is invited to christen it.

The young lady takes her position at the bow of the vessel, and as it begins its movement down

the inclined plane into the water she breaks a bottle of wine upon it, saying at the time, "I christen thee,——," mentioning the name selected. Then as the ship slides downward steam whistles blow, bells ring, and the people clap their hands as they see a huge structure weighing thousands of tons plunge deep into the water and rise again with a motion as graceful as that of a swan.

The spectator familiar with Longfellow always calls to mind, as the ship glides into her element, the beautiful verses:

> And see! she stirs!
> She starts, — she moves, — she seems to feel
> The thrill of life along her keel,
> And, spurning with her foot the ground,
> With one exulting, joyous bound,
> She leaps into the ocean's arms!

The heart of every patriotic and thoughtful spectator fills with emotion as he looks on at the launching of an American man-of-war and thinks of the vicissitudes to which she is subject. Perhaps she is to go down on some distant rock-bound coast, the captain to the last moment giving directions for the safety of the crew and nobly going down with his ship, as the gallant Herndon

did when the "Huron" sank, because there were men on board who could not be saved.

Perhaps she is to sink riddled by shot and shell, or perhaps, as we all hope, if she is ever to go into battle, she is to bear out our flag in glorious triumph. However this may be, every American onlooker feels assured that the flag which the new ship is to carry around the world will never be tarnished in the hands of the officers and men to whom her destinies are to be committed.

HILARY A. HERBERT.

THE time was the twentieth day of August, 1898, and the place was the Boylston Street side of the Boston Public Garden, opposite Church Street. Scientists attending the annual meeting of the American Association had met there as the guests of another scientist who is a member of the Boston Transit Commission. They entered an electric car. The car slipped speedily down a long incline, out of the light of day, and into a clean, cool tunnel twinkling with incandescent lights. Fourteen feet below the surface of the earth, under Boston's busiest streets, they rode to Haymarket Square, a mile distant, then back to another southern terminus at the "triangle" bounded by Tremont Street, Shawmut Avenue, and Pleasant Street.

That ride signalized the practical completion of a masterpiece of engineering; in the fullest sense a modern masterpiece, for only three and a half years before, on the 28th of March, 1895, the excavation of this great underground passage was begun.

The subway was Boston's method of solving the problem of rapid transit. It had to be solved. Fifty-six hundred street cars passed the corner of Boylston and Tremont Streets, for instance, every twenty-four hours. None of them could be dispensed with, nor could teams be prohibited from using the street. Among all the teams and street cars there was constant "congestion" at such points.

The Massachusetts Legislature of 1894 provided, therefore, for a transit commission of five members, and authorized it to expend not more than seven million dollars in the construction of a subway. Through such a channel the electric cars could be diverted, to do away with the delay

caused by blockades, and leave certain streets free for traffic.

For a part of the distance the big tunnel would underlie the edge of Boston Common. But the route was nearly two miles long, and the subway, everywhere wide enough for two car tracks, must in many places accommodate four. Excavations

going on under crowded streets must graze the foundations of tall buildings and thread a maze of water, gas, and sewer pipes and electric conduits. How was the work to be done speedily, safely, and without inconveniencing the people who used the streets?

The Transit Commission's engineers knew their business and did not try to dodge their responsibility. In order that contractors might not be overwhelmed, the subway had been divided into thirteen sections, and four of these, presenting peculiar difficulties, were in large part built by the commission itself. Where important buildings

and other structures were in close proximity the commission trusted no contractor, but itself attended to excavations. Many miles of pipes and conduits were removed under the engineers' direction, and safely relaid, some of them stowed snugly away in the subway roof.

How to avoid interference with traffic while doing these things was the other requirement of the problem. The treatment of it is fairly shown in the instance of section four, which is eleven hundred and seventy-five feet in length, and runs under Tremont Street, south of Boylston. It gives one an idea of the magnitude of this one section to know that among the details contractors had to bid upon were the excavation of about fifty thousand cubic yards of earth, the placing of twelve thousand cubic yards of brick and concrete masonry, and the setting up of five hundred tons of iron and steel work.

Trenches about twelve feet wide were opened across Tremont Street, their tops being bridged by strong beams and timbering which was flush with the surface of the street. In each trench a small portion, or "slice," of the subway was constructed. Ultimately the slices were joined.

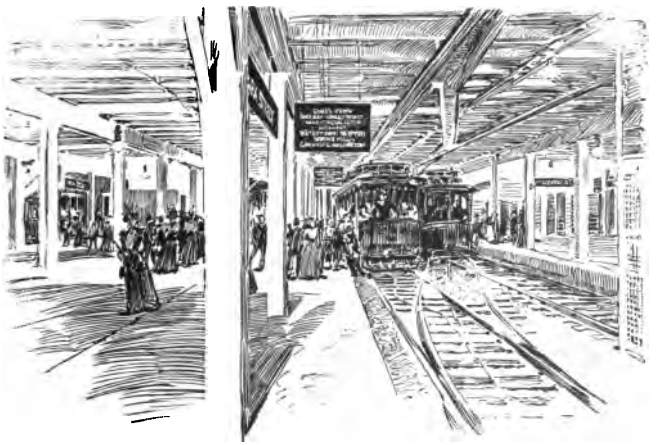
There were eighty-nine of them, by the way, in this length of less than twelve hundred feet.

Thus there was no disturbance of the street-railway tracks, and during business hours almost the whole surface of the street was kept open for traffic. In busier sections the commission did better still. Tunnels were driven on each side of the street, to lessen the amount of excavation to be done in the slices, and the dirt was taken up through narrow shafts and carted off by an overhead railway.

Three sections of the subway, extending from the Public Garden to Park Street, were first opened to the public. Somewhat later, sections four and five were opened, thus bringing into use the two "sub-subways." The illustration shows one of these, with a south-bound car passing under the Tremont Street track, near Hollis Street. The bottom

of the masonry in the "sub-subway" at this point is thirty-nine feet below the surface of the street.

There are five stations in the subway — two of them under Boston Common — and that at the Park Street corner of the Common is fairly representative of all. At such a point one begins to



realize how massive and spacious a work the subway is. Here the two platforms where passengers wait for north-bound and south-bound cars measure respectively seventy-five hundred and nine thousand square feet.

An instructive diagram in one of the Transit Commission's masterly reports shows how this

subway compares with others. The inside area of the subway utilized by the City & South London railroad is eighty-four square feet; that of the Budapest subway, one hundred and ninety-three square feet; and that of the famous Blackwall tunnel under the Thames, three hundred and fifty-two square feet. A cross section of the two-track subway under the Boylston Street side of the Common is three hundred and fifty square feet, and that of the four-track subway under the Tremont Street side of the Common is seven hundred and seven square feet.

"Owing to the fact that the construction is not of an ordinary character," the commission modestly adds, "questions not infrequently have arisen in regard to which there are no precedents to guide the commission, the contractors, or the public." But on the other hand, two excellent precedents have been established: the cost of the work has been kept far within the original estimate, and no suspicion of scandal has attached to the expenditure of these millions.

THE ST. CLAIR TUNNEL

ALMOST every boy thinks at some time in his life that he should like to be a civil engineer. He would not be a boy if he were not attracted by the manly, outdoor life and the chances of doing hard and bold things, and being a "boss." Indeed, civil engineering is a noble business; but a boy cannot understand, and few grown-up people do understand, what a dangerous, anxious, and wearing business it is.

An engineer's greatest triumphs and his hardest fights are hidden away where they are never seen. Only other engineers know much about them or understand them.

No other profession is so much like war as civil engineering. The chief engineer, like the general, must make his plans with the greatest patience and care. He must know the exact facts and guess at nothing. When he cannot avoid guessing, he must weigh all the chances with careful judgment; and when he has done his best he may

meet sudden and unlooked-for emergencies in which all his care will not save his work from ruin. Then, if he lacks courage and skill and swift and clear judgment, he may lose in an hour the honorable reputation made by a lifetime of good work.

The unexpected dangers do not often come in building structures in the open air and above ground. The difficulties that cannot be foreseen come more frequently in tunnels and deep foundations, and in building works in swift rivers and on exposed coasts.

Of all engineering work, that which is least certain is what is called subaqueous tunneling — that is, driving tunnels under rivers or other bodies of water. Usually the tunnel must be driven in clay or river silt or sand and gravel, with, in any case, more or less loose rock and bowlders. The trouble is to keep a tight roof, and, if the material is very soft, to keep the tunnel itself in shape. There is great danger that the water will break through the roof and flood the work, or that the sides of the tunnel may be crushed in by the pressure of the water and the half-fluid material beneath it.

The St. Clair tunnel is one of the most remarkable in the world. The tunnel is six thousand feet, or more than a mile, in length. Including the open cuttings on each end, the work is eleven thousand six hundred feet long. It was driven through blue clay. Above the tunnel flows a swift river, forty feet deep. Between the tunnel and the water is from fifteen to twenty feet of clay, sand, and gravel.

The novelty and magnitude of this work, the difficulties met, and the boldness and speed with which it was done, have made it a matter of great interest to engineers all over the world, and perhaps the boy who intends to be a civil engineer will also be interested in a short account of it.

The Grand Trunk railway crosses the St. Clair River from Sarnia, Ontario, to Port Huron, Michigan. On the St. Clair River there is a shipping commerce five times as great as that which passes through the Suez Canal. The river is from one half to three quarters of a mile wide, and the current flows at from six to eight miles an hour. For many years trains have been taken across on great ferry boats. This is comfortable enough for passengers, but it takes up precious time; the

boats are expensive to keep up and to operate, and in winter, when the river is full of floating ice, the delays and cost are serious.

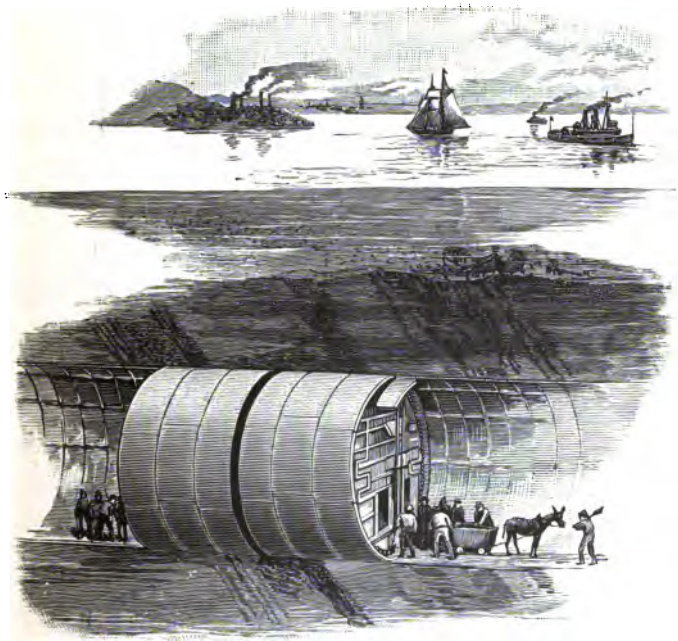
To carry the tunnel, which it was decided to build here, through clay, with occasional pockets of gravel and quicksand, and with a great river flowing only fifteen feet overhead, was a difficult problem.

Let the civil-engineering boy stop here and think how he would do it. How would he keep out the water always pressing down on the roof, and how would he keep the roof, sides, and even the bottom of his tunnel from collapsing when he struck the quicksands?

The collapse of his tunnel would not mean merely running away to begin in another place, but it would mean burying in the bottom of the river two or three million dollars, and scores, or perhaps hundreds, of men, and his own professional reputation.

It was decided to do the work inside of steel tubes, called shields, which should be pushed ahead as the work advanced, and to line the tunnel with rings of cast iron as fast as the shields went forward. In this way the danger

of collapse of the tunnel would be avoided, and it would be practically finished as fast as it was dug. But to keep the water or soft material from flowing



The Hydraulic Shield

in at the open front of the tube was another thing. How that was done will be told later.

One shield was started in from the Michigan side and one from the Canadian side. Each of

them was a tube twenty-one feet and six inches in diameter, and fifteen feet, three inches long. It was made of steel plates one inch thick. The plates at the forward end of the tube were sharpened to a cutting edge all around the circumference.

This tube was stiffened by steel plates put in up and down and crosswise, dividing the inside into square cells. Five feet from the back end of the tube was a partition, also of steel plates, in which were two square doors near the bottom. The men worked in the front part of the tube, cutting down the clay and throwing it back through the doors. Then it was loaded into small cars and hauled away to the rear on a narrow railroad track by mules or horses. There was a second track to bring in the empty cars.

As fast as the shield went forward the tunnel was lined with rings of cast iron. Each of these rings was twenty-one feet in diameter and eighteen inches long, measured in the direction of the length of the tunnel. The ring, being of less diameter than the shield, could enter the rear of it; and so there was always a complete tube of steel and iron from the face of the clay, where the men were digging, to the entrance of the tunnel.

Each of the iron rings was made of thirteen pieces of cast iron, each of which weighed about half a ton. The pieces were bolted together, and each completed ring was bolted to the one behind it, so that the tunnel was lined with a continuous tube of iron two inches thick and water-tight. The cast-iron lining weighed about twenty-seven thousand tons. The shields were pushed forward by hydraulic jacks. The hydraulic

Profile of the Tunnel

jack is a cylinder into which water or other liquid is forced; and the water, entering, pushes a piston just as the steam in a locomotive cylinder pushes the piston to one end or the other of that cylinder.

The hydraulic jack can be made to give great power. Each shield had twenty-four of these jacks in the rear end, placed in a circle close to the shell, or outside plates of the tube, and also so placed that when their pistons were thrust out they would push against the cast-iron ring forming the lining of the tunnel.

They could push with a force of three thousand tons — a power sufficient to lift up bodily a large ocean steamship. This tremendous power was found to be twice as much as was needed to force the shield forward into the clay.

At each step the shield was pushed along eighteen or twenty inches. Then a new ring was added to the tunnel lining; the clay was cut down as far as it could be done safely, and carried away. Then the shield was pushed forward another step.

This was all very simple so long as the work was under the dry land; but when it reached out under the river it was necessary to find some way to keep the water out. Otherwise, when seams of loose material were struck, water would have poured in and flooded the tunnel, and that would have ended the matter. To prevent this, compressed air was used.

Every one knows that he can hold up a column of water with a column of air. Let him fill a U-shaped glass tube half full of water, hold it upright, with the open ends upward, and blow into one end of it. The water will rise in the other leg of the tube, and the harder he blows the higher the water will rise, and the longer will be the part of the

tube free from water. Now, if one could put a fly in the dry leg of the tube and stop the end of it, the water would be held in the other leg, and the fly could move about at his pleasure, dry-shod.

This is the principle on which compressed air has long been used in deep foundations and other subaqueous work. At the St. Clair tunnel the dry leg of the tube was the tunnel, the wet leg was the river, and the workmen were the flies.

It must be remembered that in all of this description I speak of one half of the tunnel. It was built from the United States side and from the Canadian side simultaneously, and the work at each end was entirely independent of that at the other, until the headings met under the middle of the river.

A brick partition, eight feet thick, was built in the tunnel just where it passed below the edge of the river. This was to hold the air in the tunnel. The air was pumped in through tubes built in the brick partition, and the pressure was always kept up to the point where it balanced the weight of the water overhead. It will be understood that the deeper one goes, and the higher the column of water, the greater the air pressure that must be carried.

The men, mules, and clay cars went in and out of that part of the tunnel which was filled with compressed air by means of an air lock in the brick partition. This was a big tube extending through the partition with a door at each end, both doors opening against the air pressure — that is, toward the working end of the tunnel.

To get into the tunnel from without, the air in the lock was allowed to escape until the outer door could be opened. Then one entered the air lock, shut the door, and opened a valve by which compressed air from the tunnel ahead was let into the lock. When the pressure there was equal to that in the tunnel ahead, the inner door could be opened and one could pass into the tunnel. To get out the process was reversed.

The painful part of the journey is in the air lock, at the time when the pressure is changing. There people often suffer severe pain in the ears from unequal pressure on the two sides of the ear-drum, and sometimes the suffering is so great that they cannot go on.

After one has been a little while in the compressed air the pain ceases; but there is a trouble which is peculiar to working in compressed air,

and which disables a good many men and kills a few. The men call it "the bends." It is a paralysis, more or less complete, of the muscles, and especially of the muscles of the legs. Sometimes it is not painful, but more often it is so; and sometimes it is very painful indeed. At the St. Clair tunnel there were three deaths from this cause. Horses could not work in the compressed air, but mules stood it well, though occasionally one of them was visited with "the bends."

The pressure of air carried was ten pounds per square inch at first, and twenty-three pounds when the middle of the river was reached. At times it was run up to forty pounds. Of course these pressures are in addition to the normal atmospheric pressure of fifteen pounds to the square inch, which is always present on every body and every surface in the open air.

The air pressure was kept up by pumps, and to guard against accident there were two sets of air compressors at each end of the tunnel. If the supply of air had failed for a moment, the water would have rushed in and drowned the men.

Besides the air-compressing plant, machinery had to be provided for pumping out any water

that drained into the tunnel during the work, and other machinery for lighting it by electricity. There were hoisting engines and derricks with which to lift to the surface the dump cars as they came out loaded with clay.

It happened repeatedly that the shields, as they were forced forward, entered pockets of gravel or quicksand going deep down into the blue clay. Then the air would escape through the loose material, and the water would begin to flow in. Generally this could be stopped soon by increasing the quantity of air pumped in, but not always. Sometimes the air blew out through the bottom of the river so fast that the air pumps could not keep up pressure enough to stop the flow of water.

More than once it seemed as if the tunnel would be flooded in spite of all that could be done, but luckily the engineers were always able, by plastering over the face of the gravel with clay, and by working the air compressors up to a pressure of as much as forty pounds to the square inch, to hold back the water long enough to get the shield through the loose gravel into the clay beyond.

On the thirtieth day of August, 1890, the shield from the United States shore met that from

Canada, under the middle of the river. This was just one year after they started on their strange journeys; and I do not believe that Meade, on the Fourth of July, 1863, was happier or more thankful than was the chief engineer of the St. Clair tunnel on this August day.

H. G. PROUT.

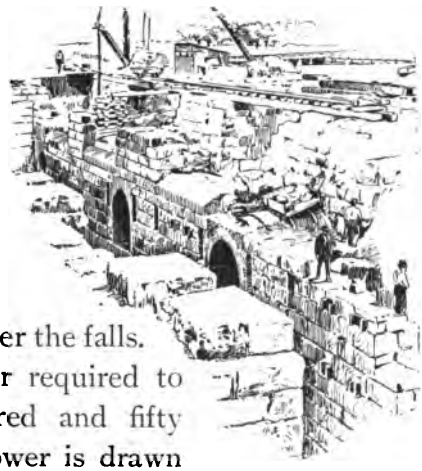
HARNESSING NIAGARA

IF you imagine a line of very strong horses, harnessed tandem, extending eight hundred and fifty miles, from Boston almost to Chicago, all pulling steadily, you will get some idea of the amount of power which it is expected will soon be taken from Niagara Falls by water wheels and distributed, chiefly in the form of electricity.

Millions of dollars have been spent already in digging the tunnel and wheel pit from which the first installment of the power is to be supplied; and much more money will have to be used to develop the full four hundred and fifty thousand horse power for which the plans provide.

No one can tell at present just how far this enormous force will be sent; but some of the best engineers believe that it will be made to turn mill wheels, light streets, and even light and heat houses throughout the greater part of New York state, a large territory in Canada, and perhaps here and there in neighboring states.

Yet the great cataract will not be robbed of much of its strength; for it is estimated that the horse power of Niagara Falls is nearly five million nine hundred thousand — the greatest that Nature has concentrated at any one place on the globe. It has been said that all the coal mined in the world would barely supply the steam pumps that would be needed to pump back the water that flows over the falls.



The Work in Progress

When the water required to create four hundred and fifty thousand horse power is drawn from the river above the falls and sent to the gorge below by a short cut through tunnels, the great cataract will be lowered about seven inches only, and the loss will hardly be noticed.

Plans for using Niagara Falls to run machinery had been considered for half a century, but it was only recently that the necessary permission to use

Niagara water was asked, and obtained, from the New York Legislature. Four years later money for the undertaking had been supplied by capitalists and banking houses.

An International Niagara Commission, under the presidency of Sir William Thomson, now Lord Kelvin, of England, was formed to invite the leading engineers of Europe and America to submit plans for harnessing the cataract without marring its beauty. Twenty-six plans were submitted, and from these the company's engineers devised the designs finally adopted.

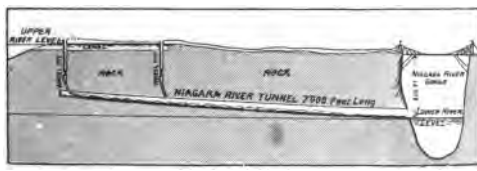
On Oct. 4, 1890, the first spadeful of earth was dug, and from that time on the work has been hurried with all possible speed.

Told in the simplest way, the undertaking consists of a number of deep holes in the ground, one much larger than the rest, each with water wheels at the bottom. The water from the Niagara River is to be carried to these pits by a canal, led down to the wheels in pipes and then off to the lower river through a tunnel which connects all the pits.

All who have visited Niagara will remember that the river turns almost at a right angle at the falls. The tunnel, stretching from a point near

the river a mile and a half upstream from the American Fall to a point about one thousand feet below the American Fall, forms, roughly, the hypothenuse of a right-angled triangle, the falls being at the right angle.

The canal through which water from Niagara will flow to the tunnel leads up from the river about two thousand feet. Along the sides are a score of inlets controlled by massive gates. Ten inlets open through the thick masonry which lines



the main wheel pit, and each will lead into a steel pipe called a penstock, about as large around as an ordinary street car.

The penstocks run straight down one hundred and forty feet and discharge into a turbine, consisting of a pair of water wheels, the shaft of which extends upward beside the penstock into the power house built directly over the pit.

When one of the gates is raised by a delicate electrical apparatus which controls it, water from

the canal will pour in and flow down the penstock, or water pipe, pressing into the turbine with a force of five thousand horse power. After passing through the wheels the water will travel on from a discharge tunnel at the end of the wheel pit out into the main tunnel.

The largest pit, which was completed on the first day of January, 1894, is one hundred and seventy-eight feet deep, twenty-one feet wide, and one hundred and forty feet long. At present there is room for only four penstocks.

It is not easy to imagine a hole pulled up out of the ground, but the masonry that lines this wheel pit is so thick and strong that if the pit could be pulled up its walls probably would stand firm like a giant chimney.

The chief interest lies in this main wheel pit, for it is here that electricity is to be generated for distribution throughout the neighboring country.

The smaller pits are to supply water power direct to the various mills that will cluster around the inlet canal. The turbines at the bottom of one of these smaller pits are now turning the wheels of the largest paper mill in the world.

The tunnel itself simply carries off the water that has done its appointed work. Yet its construction has been the most difficult part of the whole undertaking, keeping many hundred men busy more than two years, costing in round numbers a million and a quarter dollars; and worse yet, costing twenty-seven lives, through various accidents.

The tunnel slopes gently down from the bottom of the wheel pit to the portal, just beyond the new suspension bridge, a mile and a third distant, passing beneath the busiest part of the city of Niagara Falls and almost directly under the Central Railroad station, where most visitors to the falls alight.

The tunnel is shaped like a horseshoe; it is twenty-one feet high, eighteen feet and ten inches

across the broadest part, and nearly four feet narrower at the bottom. Its whole length was blasted and dug through limestone rock and shale, of which enough was taken out to make twenty acres of valuable real estate, when dumped along the shore of the river. This rocky river bed, two hundred feet underground, is lined with from four to six rings of brick especially prepared to resist wear and tear by the water.

The portal from which the water flows into the river looks from above like a commonplace black hole down by the water's edge. Yet it is said to be one of the most solid pieces of masonry ever built. It rests on a ledge of sandstone forty feet below the level of the river, and is built up as strongly as steel and stone and cement can make it. It is well that it should be strong, for it must withstand for many years to come not only the action of the current without, which boils and foams as it swirls down from the rocks below the falls, but also the tearing rush of the waters within, which will enter upon a steep incline as they approach the end of the tunnel.

More has been said about electricity in connection with this power plant than about any other

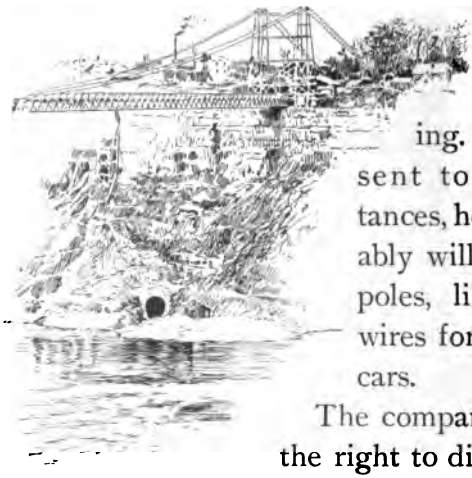
branch of the work. I have scarcely mentioned it yet, because it has nothing to do with the creation of the power, and little to do with the mills at Niagara Falls. Its part will be played chiefly in the distribution of power to other cities.

The shaft from each turbine down to the main wheel pit extends up through the floor of the power house,. and will turn the revolving part of a dynamo capable of converting five thousand horse power into the form of electricity, which can be sent easily over wires for many miles in any direction, and at the end of its journey can be changed back into the original form of power.

The process is a good deal like sending money by mail. Silver dollars cannot be carried easily in a letter, but they may be exchanged for a money order which, at the end of its journey, can be changed back into silver dollars.

Those who saw, at the World's Fair, the twenty-one hundred horse power dynamo in the Intra-Mural electric railway's power house, were told that it was the mightiest machine of the kind ever built. So it was then; but it would take more than two dynamos like it to do the work of one of the many that soon will be whirring here.

Each dynamo has its own water gate, water pipe, water wheel, and shaft, forming practically separate and independent power plants good for five thousand horse power each. For a short distance, at least, the electric current is to be sent out on underground wires carried in a subway big enough to walk through without stooping. When it is sent to greater distances, however, it probably will be carried on poles, like the trolley wires for electric street cars.



The Outlet

The company has secured the right to dig another tunnel of the same size as the present one, with wheel pits to match, and will begin work on it as soon as it is needed. When the second tunnel is finished two hundred thousand horse power can be supplied.

Beside this, practically the same company has bought permission from the Canadian government

to dig two wheel pits and tunnels on the Canada side, solely for the generation of electricity.

The first of these wheel pits and the power house to match will be built, according to present plans, close to the brink of the Horseshoe Fall, at the foot of the high bank directly underneath the Falls View station. The tunnel will slope down from the bottom of the pit four hundred feet to the river below the fall.

Each of the Canadian tunnels is to carry away the water needed to generate one hundred and twenty-five thousand horse power. The total capacity of the plants to be built on both sides of the river will be, therefore, four hundred and fifty thousand.

The chief uncertainty about electricity is that it seems to leak from the wires. The longer the journey it makes the more of it is lost by the way, and consequently the more it will cost. The expense of sending it by wire or subway is also heavy. A great deal depends on this question of price.

How far can electricity be sent without a loss that will make its cost equal to steam power? Upon that question it depends whether Niagara's

power shall be used only near the great cataract, or whether it shall be sent broadcast. Inventions have been made recently which, it is believed,—by the inventors, at least,—will make it possible to carry electricity a great distance

without a loss large enough to make its cost equal that of coal.

Nikola Tesla, the brilliant young electrician who astonished scientists by proving that an electrical current can be created which will pass through the upper air without wires to conduct it, says, " The current from Niagara Falls can be

taken as far as New York City without great loss, and I believe that before long we shall be able to take it to any distance."

CURTIS BROWN.

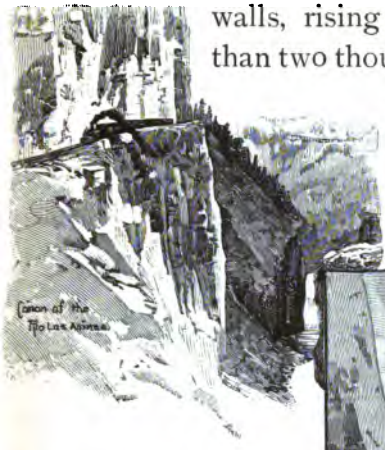
NOTE. — On May 16, 1896, an electric current generated by Niagara Falls and transmitted through a wire to the electrical exhibition building in New York, was employed to start a message on a circuit of twenty-seven thousand miles. The message consisted of these words: "God creates, nature treasures, science utilizes electric power for the grandeur of nations and the peace of the world." From New York the message went to Chicago, Los Angeles, Vancouver, Montreal, and Canso. The words were then taken up by the Atlantic cable and transmitted to London, from which point they flashed on through Lisbon, Gibraltar, Malta, Suez, Bombay, and Singapore, to Tokyo. From Japan they were returned to London, and fifty minutes after they had left New York Thomas A. Edison received them back again from the wire in the exhibition building. The larger part of this time had been expended in retransmitting the message at several points along the route, where a change was necessary from land to cable lines and *vice versa*.

WHERE RAILROADS GO

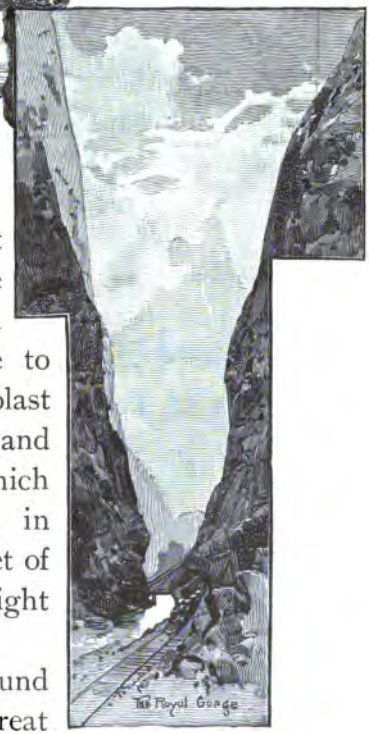
THE railroads of the Rocky Mountains present some of the most wonderful examples of skillful engineering in the world, and they carry passengers past scenery unsurpassed in grandeur.

Even those travelers who have gone through the Grand Cañon of the Arkansas in Colorado on the Denver and Rio Grande railroad, and who have been awed by its silent and gloomy splendor, may not know that before the railroad was built the narrow river filled the space between the rocky walls so that neither man nor beast could enter. There was not even a footpath by the river's brink, and no boat could navigate its shallow but turbulent waters, which were choked with mighty bowlders.

The construction of the Denver and Rio Grande railroad was begun in 1870. It was a mighty undertaking. Entering the cañon from the little town of Cañon City at its mouth, one is almost immediately shut in by two nearly perpendicular



walls, rising now and then more than two thousand feet. The road-bed in some places is cut out of the solid rock; in others it lies on rocky grades made in the river bed. At times the laborers were lowered by ropes from the high walls above to drill and quarry and blast out a line for the road, and in the entire cañon, which is about eight miles in length, hardly forty feet of the track lie in a straight line.



The road winds around sharp curves under great

overhanging rocks; it crosses and recrosses the noisy little stream, made narrower and noisier by the roadbed, which has encroached on a right of way that was never before disputed.

Another line of mountain railroad of great interest is the La Veta Pass line that runs over the Sangre de Cristo mountain range. Here an elevation of nearly twenty-four hundred feet is reached in thirteen miles, and at one point the grade is more than two hundred feet to the mile for a distance of three miles. Before the pass is reached the Spanish peaks are seen rising above the other mountain summits to heights of twelve and thirteen thousand feet. They stand apart from the other summits, rugged and majestic.

The Denver and South Park line of railroad, reaching to the Gunnison country, passes through a tunnel seventeen hundred feet long, at the great height of eleven thousand feet. What a victory over natural obstacles this means can only be understood by those who have gone over this line of road. Passengers glancing out of the car windows hold their breath in places where the train seems to be clinging to the mountain wall thousands of feet above the dark and gloomy cañons below.

One may ride many miles on these wonderful railroads without seeing a house, and the stations are often many miles apart. The "towns" and "cities," when reached, sometimes consist of a single house.

I remember one such city away up on the summit of a mountain ten thousand feet high. The engine behind which I rode went panting and puffing up to it one bright day in June ten years ago. The last mile of the ascent was a steady pull up the steep and flinty side of the mountain.

Whirling suddenly around a curve, the ascent became less abrupt, and we stopped before a tiny station, painted bright blue, standing on a bit of level ground a few feet square. There were bright red calico curtains with white lace borders at the windows, in which were plants in bloom. Through the open door one caught a glimpse of a tidy little room, a bright rag carpet, and walls covered with gay pictures.

A tidy little woman, too, with the whitest of aprons and the starchiest of calico dresses, came to the door, on the step of which a fine old Maltese cat lay asleep in the sunshine. A canary sang shrilly within, and just before we went on

our way a curly-headed baby came creeping across the floor, and was caught up in its mother's arms to wave us a good-by with one of its chubby hands.

In another moment we were rushing down the mountain side to the gloomy gulch below, leaving far behind us that pretty picture of home life in the sunshine of the heights.

Perhaps railroads go to more remarkable places in Colorado than in any other state in the Union; but in California there are railroad wonders scarcely less noteworthy.

The passenger who, for the first time, climbs the Tehichipa Summit pass on the Southern Pacific railroad is astonished, after he has left behind him the level lands of the San Joaquin valley and is scaling veritable mountain heights, to find the train crossing another railroad track, though at a height considerably above it. "Can it be possible," the passenger asks, "that there is another railroad running along the top of this lonely mountain in the wilderness?"

Then he is told by some fellow-passenger, probably with a smile, that he is crossing the track that he has just ridden over. The road has made

a loop upon itself; and while the train, in making the circuit of this loop, has not progressed at all toward its destination, it has risen a good many feet higher toward the summit which it must climb before it starts on its descent.

If Colorado and California are the states where aërial railways abound, West Virginia may well be called the state of railroads under ground. A single railroad, the Baltimore and Ohio, has forty-four tunnels on its line, most of which are in West Virginia.

We must, however, go out of the United States, but not away from American soil, to find the most remarkable railroad tunneling, in some respects, in the world. In Peru, on the Lima and Oroya railroad, there are sixty tunnels on one hundred miles of railroad; and here we find a great tunnel, almost four thousand feet long, which is more than fifteen thousand feet above tide water — two miles higher than either of the famous Alpine tunnels, the St. Gotthard and the Mont Cenis. With railroads in the air, under ground, and under water, it seems hard to find any place where they do not go.

J. L. HARBOUR.

ARTESIAN WELLS

UNLIKE ordinary wells, the artesian well is a very narrow hole from three to eight inches in diameter; it resembles a small tube carried to a vast depth. The principle upon which this well works is the tendency of flowing water to rise to the level of its source.

In some unknown way it was discovered that streams of water percolate from elevated lands into the lower strata or layers of the earth's crust, and are there confined, probably gaining an outlet into the sea, since currents of fresh water are sometimes found entering the ocean below the surface. The tapping of these hidden streams gives vent to the water, which at once springs up with great force, sometimes rising many feet above the mouth of the well.

It is, therefore, a first condition, in searching for a spot suitable for an artesian well, that there shall be a source higher than the place where it is proposed to bore for water; but the slope or dip

of the strata containing the water should be moderate rather than steep, lest the flow of water be beyond the reach of the boring.

The strata should also be in alternate layers of porous earth and rock. A supply obtained from such a source may be considered as practically inexhaustible, and unaffected by the variations attending the water supply near the surface of the earth.

The process of boring an artesian well is ingenious, and requires great patience and perseverance. Any one who has watched the slow process of drilling holes in rock blasting may form some notion of what it must be to bore through strata of rocks sometimes to the depth of more than two thousand feet.

The idea of making artesian wells comes to us from France, where they were first sunk in the province of Artois, from which they take their name. There they were known as long ago as the twelfth century; but, as in the case of many other inventions, the Chinese probably deserve the credit of being the first to employ this method of obtaining an unfailing water supply. More than two thousand years ago artesian wells were

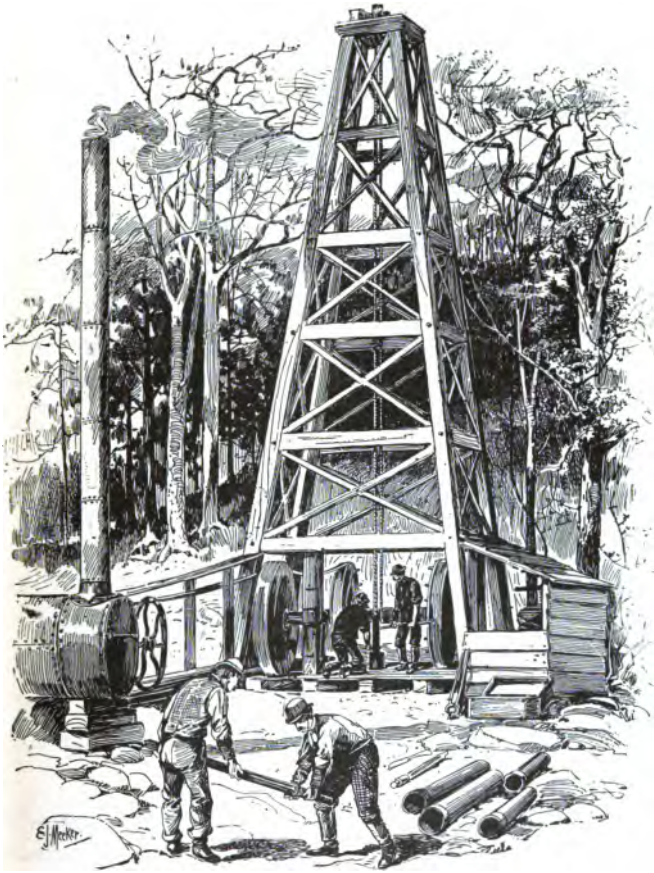
known in China for obtaining water and petroleum, and were sunk to an immense depth.

In a single province of western China such wells are found by tens of thousands. To drill so many with simple manual apparatus could only be possible in that land of infinite patience, where time and labor are of little account.

The Chinese appliance for boring consists of a heavy cutting drill, joined to a massive iron rod six feet long and four inches in diameter. A cylindrical chamber around the drill, supplied with valves, receives the fragments of earth and rock. The drill is driven by means of a windlass moved by men or by a horse.

The Chinese are now far behind the rest of the world in this business, since the steam engine has been brought to the aid of the boring mechanism. Moreover, aside from the use of steam power, the entire system of tools employed in Europe and America is more delicate and complicated than the rude drills and windlasses of China.

Over the proposed site of a well a wooden or iron derrick or frame is erected, from twenty-five to sixty feet high and from twelve to eighteen feet square at the base, narrowing nearly to a point at



Making an Artesian Well

the top. Upon this rests a frame for the support of the pulley, over which the drill rope turns. The rope is led to a shaft on the ground fixed on journals or grooves. Around this shaft the rope is coiled, and at each end of it is a pulley called a "bull wheel." The power is applied to the bull wheel. The drill is attached to the upper end or fall of the rope. When a very deep cutting is to be made the drill is preceded by a heavy iron pipe called the "drive pipe." This is forced down by heavy weights, and is five to eight inches in diameter. It is driven in sections ten feet long, and as it is in the nature of a guide to the drill, — being, in fact, a sheathing to the bore, — great care is necessary that it shall be exactly perpendicular.

The power is applied directly to the drills by a heavy timber called the "working beam," which turns on an upright called the "Samson post." The working beam is moved by a crank attached by a connecting rod to the shaft of the driving wheel.

Such is the method of applying the power to the boring drills. These are of various sorts, including a large variety of implements to suit the unequal depths and the differences in the nature

of the strata. While some portions of the bore pass through hard rock, others are cut through beds of clay or sand, which sometimes mixes with water and chokes the bore and the valves.

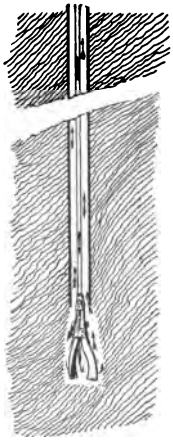
One of the most important implements used in digging an artesian well must, therefore, be the sand pump, which is used in any case after every cutting of ten or twelve inches, to remove the fragments of earth and rock displaced. It is an iron tube having the lower end closed by a valve

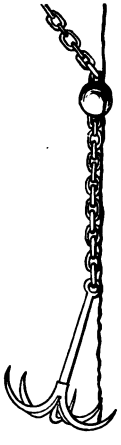
opening upward. It is raised by a light rope, and the contents tell the story of the progress of the work through the different strata.

Other implements of importance are the tools necessary to extract broken drills, or drills and suction pumps that have parted from the rope. Such accidents are especially likely to happen if a stratum of mud or quicksand buries the tool and causes a sundering of the rope.

When one considers what it is for a drill to be one thousand feet down at the bottom of a hole only five or six inches in diameter, he must feel that it would be impossible to seize and raise such an

obstruction, and that the work must be effectually blocked. Very ingenious means have been devised for overcoming such difficulties; grappling irons, catches forced together by springs, hooks, and tools resembling a dentist's forceps have been provided, and the workers are not easily dismayed.





Even with such aid, however, the difficulty of removing obstructions from the bore of an artesian well is great. When the boring of the famous well of Grenelle, near Paris, had reached a depth exceeding twelve hundred feet, the drill broke and fell, with nearly three hundred feet of rod, to the

bottom. No less than fifteen months were spent in breaking up and removing the fragments of the rod before the work could be resumed.

When, for some unknown reason, the supply of water or oil obtained does not equal the expectation, and it is assumed that the well has become choked, a torpedo is lowered to the bottom. The well is then flooded, and the torpedo exploded by an electric spark. This method often increases the flow from five per cent to one hundred per cent. One of the deepest of artesian wells is that of Louisville, Ky., which has a three-inch bore and is more than two thousand feet deep. The yield is upward of three hundred thousand gallons a day. The well of Grenelle, nearly two thousand feet deep, yields five hundred thousand gallons a day. The well at Charleston, S.C., is remarkable not so much for its depth as for the great difficulties which were encountered and overcome in its construction. For several hundred feet the bore ran through loose alluvial sands alternating with rock. It was found necessary to sheathe seven hundred feet with a sheet-iron tubing. At the depth of about a thousand feet sand flowed in again; all the tubing had to be

removed and replaced with heavier tubes, four inches in diameter, screwed together.

Many of our cities are supplied with artesian wells, and a number of large hotels obtain their water supply from artesian wells upon their own premises.

This means of obtaining water is extensively used in dry countries. What is remarkable is the fact that artesian wells are gradually transforming certain portions of the arid wastes of the Desert of Sahara. At one spot one hundred and seventy thousand palm trees are the result of such wells sunk in previously arid wastes.

The Shah of Persia has, within a few years, granted a concession to an American company for furnishing that country with artesian wells. Although the results have not proved entirely satisfactory, owing partly to financial reasons, there is little doubt that in time Persia will be greatly benefited by the digging of artesian wells in its arid plains.

S. G. W. Benjamin.

THE MARINERS' COMPASS

"Do not speak to the man at the wheel" is printed on the wheelhouse of many seagoing steamers. Why must we not speak to the man at the wheel?

Because, during his two hours' turn, his attention ought to be fixed upon his compass. Let him turn to a passenger to answer a question, and the vessel will depart slightly from her course. Time will be lost, force will be wasted, and the steersman will hear a short, sharp word from the officer of the deck, calling him back to his duty.

The compass is the very eye of the ship. It is the compass that enables the captain to shoot his arrowy steamer over the trackless Atlantic in less than a week, through fog, darkness, and storm, without swerving from his course.

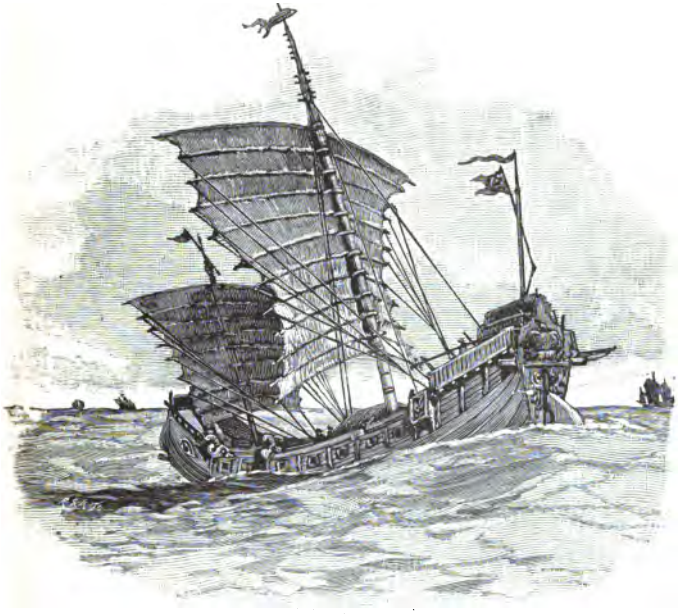
Man possesses few instruments more valuable than this, and yet no one knows who invented it. If we ask the Chinese, the people who invented so many useful things, they point to some obscure

passages in their ancient books, which do not prove their claim. If the Chinese had the compass, why did they not use it? From time immemorial their lumbering junks hugged the shore, and rarely ventured farther out to sea than to Japan, which is only a few miles from the coast of Asia.

If we ask the Greeks, we begin to get a little light on the subject, for the Greeks at least knew something of the attractive power of the magnet.

They tell us, in their mythological way, that a shepherd named Magnes, while pasturing his flock upon Mount Ida, found one day that the iron at the end of his staff adhered to the ground, as did the nails upon his shoes. He picked up some of the dark-colored stones under his feet, brought them home with him, and thus gave to mankind a knowledge of the magnet, which was named after him. The Greeks were great story-tellers. They had their legends about everything, and this about Magnes is one of them, from which we can at least learn that they were acquainted with the magnet's power of attraction; but they knew nothing of that valuable quality which it imparts to the needle of the compass. They knew no method of steering vessels in the open

sea except by the stars, the flight of birds, and glimpses of the distant headlands.



Chinese Junk

Nor did the Romans. The Roman writers were lost in wonder at the magnet's attractive power, but there their knowledge of it ended. The elder Pliny speaks of it with the simple amusement of a little child.

"What is there in existence," he asks, "more inert than a piece of rigid stone? And yet, behold! Nature has here endowed stone with both sense and hands. What is there more stubborn than hard iron? Nature has in this instance bestowed upon it both feet and intelligence. It allows itself, in fact, to be attracted by the magnet. . . . The moment the metal comes near it, it springs toward the magnet, and, as it clasps it, is held fast in the magnet's embraces."

It was at some time near the end of the twelfth century of the Christian era that the mysterious power of the magnet upon the needle became known to a few of the learned men of Europe. Probably the knowledge of it was brought to them by the crusaders returning from the Holy Land, and there is much reason to believe that this power of the magnet was first observed by the Arabs, an ingenious race and the most skillful travelers in the Middle Ages, whether on land or sea. The crusaders began to return home in numbers about A.D. 1100, and the knowledge of the magnetic needle gradually spread over the north of Europe. The bold Norwegians seem to have been the first to use the needle in navigating the sea.

In the year 1258 a learned Italian, named Brunetto Latini, who was afterwards tutor to the poet Dante, traveled in England, and visited at Oxford Roger Bacon, a man devoted to the pursuit of science.

Latini wrote letters home to his friends, in one of which he says that Bacon showed him, among other things, "a black, ugly stone called a magnet, which has the surprising property of drawing iron to it, and upon which if a needle be rubbed and afterwards fastened to a straw, so that it shall swim upon water, the needle will instantly turn toward the pole star; so that, be the night ever so dark, neither moon nor star visible, yet shall the mariner be able, by the help of this needle, to steer his vessel aright."

Here we have the fact plainly stated, as it had been known to a few persons in England and France for many years. Roger Bacon imparted this knowledge to the Italian traveler as a dreadful secret, perilous to disclose to the common people, and still more perilous to make known to the ordinary priests of the age.

"This discovery," continues Latini, "which appears useful in so great a degree to all who

travel by sea, must remain concealed until other times; because no master mariner dares to use it, lest he should fall under the supposition of being a magician; nor would even the sailors venture themselves out to sea under his command, if he took with him an instrument which carries so great an appearance of being constructed under the influence of some infernal spirit."

These two learned men conversed upon this wondrous quality of the magnet, and they looked forward to some happier time, when men should be more enlightened and not afraid to make researches in natural science.

Neither Bacon nor Latini lived to see that better time for which they hoped. When they had been dead a hundred and fifty years the Portuguese, under Prince Henry the Navigator, were using the compass in their voyages down the African coast. In a few years the Madeiras and the other Atlantic groups were discovered by its assistance.

The Cape of Good Hope was rounded, and India reached by sea. One of the mariners formed in the school of Prince Henry was a man destined to put the compass to the sublime use of discovering a new world.

On the Bridge of an Ocean Steamship

Seamen did not long employ so awkward an instrument as a needle floating in a straw on a basin of water. About the year 1360 an Italian navigator constructed a compass such as we now commonly have, a needle mounted upon a pivot and inclosed in a box.

These were admirable improvements, and made such an impression that the improver is frequently spoken of as the inventor of the compass. The true inventor was the unknown man who first observed that a needle, rubbed by the magnet, has an inclination to point to the north.

One curious fact remains to be mentioned. The modern compasses, those used in the naval services of Europe and America, as well as by the Atlantic steamships, resemble in principle the needle and floating straw mentioned by Roger Bacon. Ritchie's "liquid compass" has the needle inclosed in a thin round metal case, air-tight, which floats upon liquid and has also the support of a pivot. The needle, being upheld by the liquid, can be heavier, and thus have a more powerful directing force.

JAMES PARTON.

G&Co